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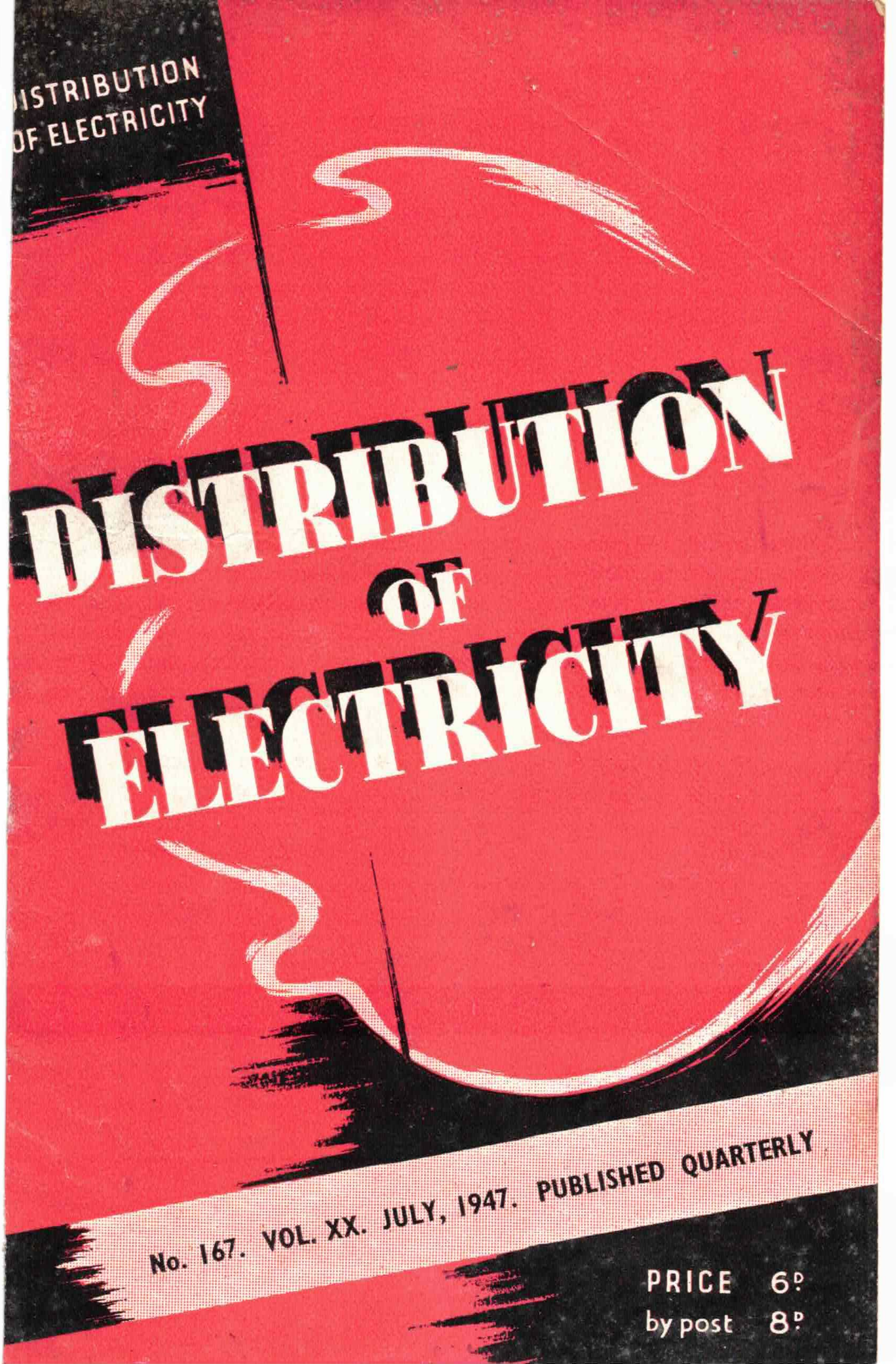

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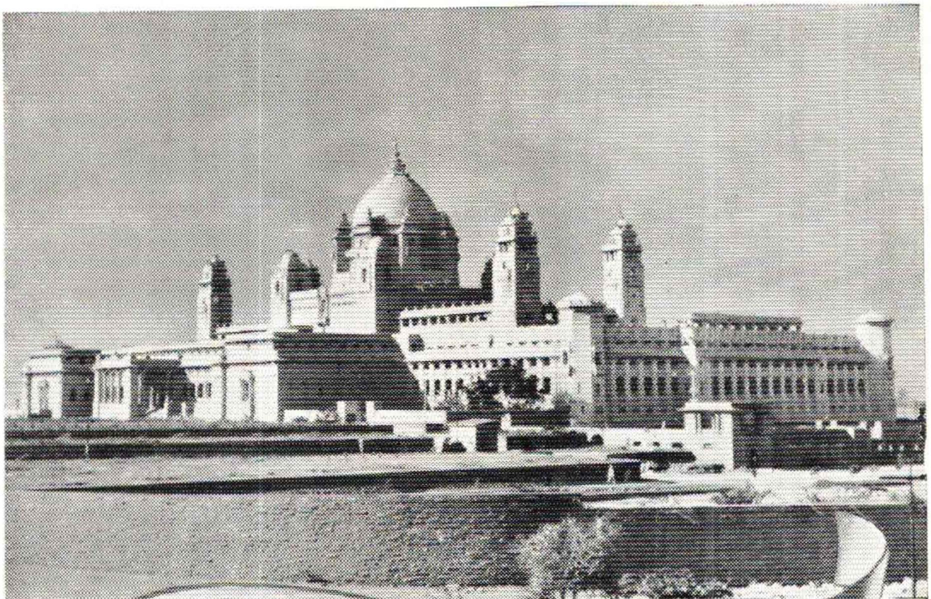

UMAID BHAWAN ★

This immense and luxurious edifice, the Palace of H.H. The Maharaja of Jodhpur, possesses the intriguing name of Umaid Bhawan, and stands on the Chittar Hill in the State of Jodhpur. It is fitting that for the electrical installation of this imposing Palace, Henley Cables were used exclusively as in many other famous buildings in India.

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★ UMAID BHAWAN may be freely translated as *"The Palace of the present Ruler of Jodhpur State"*

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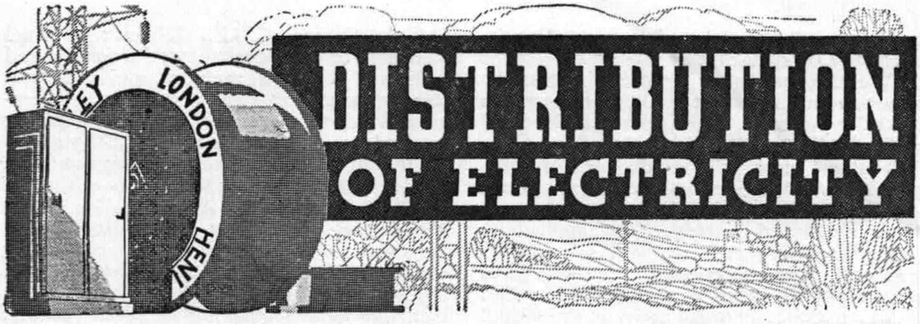

DISTRIBUTION OF ELECTRICITY

VOL. XX. No. 167 JULY, 1947. *Issued Quarterly 2/8 per annum*

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We do not necessarily agree with the opinions expressed by authors of articles appearing in this Journal.

Editorial

The I.M.E.A. Convention

Writing these words before the opening of the I.M.E.A. Convention, although they will not appear in print until the Convention is drawing to a close, we are not in a position to record the achievements of what we are sure will have proved to be a highly successful gathering.

This year's Convention, which marks the close of a year of extreme difficulty, during which the Presidential Office has been ably filled by Mr. J. S. Pickles, B.Sc., M.I.E.E., may mark also, perhaps, the termination of the long series of I.M.E.A. Conventions which have served as milestones in the progress of the Association. With the fruition of the Government's plans for nationalizing the electricity supply industry, there seems little chance of a survival of the Incorporated Municipal Electrical Association, at least in its present form. Let us hope, however, that ways and means will be found for continuing to hold some annual function at which those responsible for electricity supply up and down the country will have opportunities of meeting together in friendly intercourse and to discuss in unofficial and informal talks, problems related to their work.

We are privileged to reproduce in this issue a personal message to "DISTRIBUTION" readers from Mr. J. S. Pickles, 1947 Convention President.

132kV Cable Installations

Amongst the many items mentioned in the C.E.B. report for 1946 in relation to new types of equipment put into service, we are interested to note that the gas pressure cables installed in the Grid system have continued to work satisfactorily. It will be recalled that Henley 132 kV Gas Cushion Cable installations on the C.E.B.'s system have been described previously in "DISTRIBUTION OF ELECTRICITY."

We also note with particular interest the reference in the report to impulse tests on 132 kV cables with their associated joints and sealing ends. The Board is satisfied that these installations meet their requirement of withstanding an impulse of 640 kV. Here again it will be recalled that, in our issue of April, 1944, details of impulse tests applied to Henley Gas Cushion Cable, with its joints and terminals, were described. The test-piece successfully withstood many 640 kV impulses and it subsequently broke down on the second application of 770 kV peak. During the course of the various tests, over fifty impulses up to 740 kV had been applied to the test-piece.

In this issue Mr. T. R. P. Harrison describes the 1 200 000 V impulse plant installed in the Henley Research Laboratories. It is believed to be the only one of its kind so far installed in this country expressly for high voltage cable development work. Mr. A. W. Stannett contributes an instructive article which gives a method of calculating transient voltages in a cable resulting from an incident disturbance.

Henley's New Factory Site

In 1945 Henley's acquired a factory at Birtley, County Durham, and have since been producing certain classes of electric cables at this small factory to augment the output from their southern factories at North Woolwich and Gravesend. They have now acquired an extensive site at Newtown, a few miles to the south of Birtley. On this virgin site, which is situated in a Government "development area," a start has already been made on the civil engineering work. Arrangements have been made to proceed with the erection of the new cable factory as quickly as possible.

Our Birthday Number

With this issue, "DISTRIBUTION OF ELECTRICITY" celebrates its nineteenth birthday. The first issue was published in July, 1928, and although in the exigencies of the war period and the limitations imposed by curtailment of paper supplies prevented our maintaining monthly appearances after September, 1939, we have continued to appear as a quarterly publication without a break.

We look forward to the day—not yet in sight unfortunately—when we shall be able to revert to monthly issues, and take this opportunity of thanking all those who have supported us in any way during our infant and adolescent years.

Quality of Coal

Speaking to the North Western Fuel Luncheon Club at Manchester recently, Dr. A. Parker, C.B.E., Director of Fuel Research, of the Department of Scientific and Industrial Research, said that quality in coal was almost as important as quantity. Underground in this country we had sufficient workable coal to last for at least 200 years.

In addition to the fall in output there had undoubtedly been a reduction in quality of coal. This meant that the figures for annual output were not strictly comparable ; it had been asserted that the average ash content by weight of the coal supplied today was 5% higher than in 1938—39. Owing to insufficient data this figure could not be given reliably, but there had definitely been an increase in ash content.

Makers of plant for using or treating coal, and the plant operators, could not achieve the most suitable designs of plant and methods of operation until they had more information than at present about grades and qualities of coal likely to be available for their purposes.

Boilers at some power stations had to be shut down for drastic and expensive cleaning after operation for less than 1 000 hours owing to the deposition of large quantities of solid matter on the heating surfaces of the generator tubes, superheaters, and economizers. This had meant that boilers had been out of action for an appreciable part of the year.

British Standards

B.S. Nos. 88, 1361 and 1362 Electric Fuses.

Three important specifications for electric fuses have recently been published by the British Standards Institution.

The first of these is B.S. 88, 1947, which is a revision of the 1939 edition of the well known B.S. 88.

The other two specifications relate to low-voltage cartridge fuses (B.S. 1361:1947) intended primarily for use in consumers' units in dwelling houses, blocks of flats and office buildings, and low-voltage cartridge fuse-links (B.S. 1362:1947) designed primarily for use in plugs complying with the new specification (B.S. 1363) for fused plugs and shuttered socket-outlets. Price 2/- each specification.

B.S. 125 : 1947 Hard-Drawn Copper Solid and Stranded Circular Conductors for Over-Head Power Transmission Purposes.

The British Standard for copper and hard-drawn copper conductors for overhead power lines (B.S. 125), first published in 1924, has just been revised and published as B.S. 125: 1947. Price 2/-.

These publications may be obtained from the Publication Sales Department, British Standards Institution, 28 Victoria Street, London, S.W.1.

The I.M.E.A. Convention 1947

A Message from the President

Nationalisation will not of itself work miracles. It can do no more than provide the framework, but real success depends on human factors, the most vital of which are good management, the right spirit in the industry, and public goodwill.

These are the considerations on which the success of all commercial enterprises depend. Our industry has always been a happy one, and all existing personnel should individually endeavour in every possible way to carry forward into re-organisation the same enthusiasm and spirit that have made the industry so successful in the past.

MR. J. S. PICKLES, B.SC., M.I.E.E.
President I.M.E.A. 1946—1947.

J. S. Pickles.

MR. John S. Pickles, B.Sc., M.I.E.E., County Electrical Engineer, Dumfries, was elected President of the Incorporated Municipal Electrical Association at the Ordinary General Meeting held in Blackpool on the 28th June, 1946.

He took his degree at Manchester University in 1921 after demobilisation from the R.A.F. and joined the Yorkshire Electric Power Company where he remained until 1931. In 1931 he was appointed to his present post as County Electrical Engineer, Dumfries, where he has been responsible for an outstanding scheme of rural electrification covering the entire County of Dumfries, an area of upwards of 1 000 square miles.

He was Chairman of the Scottish Centre of the I.M.E.A. from 1939 to 1941, and Chairman of the same Centre of E.D.A. in 1942 and 1943. He has contributed two Papers on Rural Electrification to the Institution of Electrical Engineers in 1937 and 1946, and has given a wireless broadcast on the same subject.

Mr. Pickles' favourite sports are cricket and golf and his hobby is gardening.

The Henley 1 200 000 Volt Impulse Testing Plant

Part II. The Impulse Generator

By T. R. P. HARRISON, B.Sc.Tech., M.I.E.E.
Henley Research Laboratories

HAVING outlined in Part I the special features which must be borne in mind when considering impulse testing in connection with cable samples of relatively high capacity, a description will now be given of the impulse generator recently installed in the Henley High Voltage Research Laboratory, showing how the principles outlined are applied in practice.

A general idea of the plant is best obtained from Fig. 1 which shows the D.C. charging unit on the left, the main condenser bank with spark gaps in the centre and the capacity potential-divider in the right foreground. The low voltage A.C. supply is fed to the generator through a contactor panel and moving-coil regulator situated near the D.C. charging unit remotely controlled from a control desk situated in the control room overlooking the area.

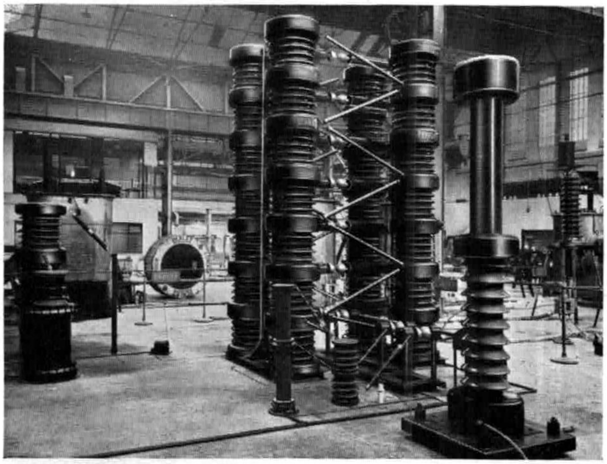

FIG. 1.
Complete 1 200 000 *kV Impulse Plant Showing D.C. Charging Plant and Capacity Potential Divider.*

Charging Unit

Fig. 2 shows the charging unit for the main condenser bank. This unit consists of a transformer and condenser on the left, a rectifier bank in the centre, and a connection to the condenser bank is visible on the right.

The incoming 50 cycle supply is fed through a 10 kVA 0—250 volt moving-coil regulator driven by an oil-immersed disc motor and the output of this regulator is connected to the primary of the 6 kVA 80 kV transformer. This transformer is of novel design as the core operates at a potential half that of the output. The top plate is the high voltage terminal and situated on this plate is an oil-immersed porcelain clad 0·015 μF. condenser rated at 100 kV D.C. The supply from the top plate of this condenser is taken through a resistance to the mid-point of the pair of oil-immersed porcelain clad selenium rectifiers, each of which is rated at 200 kV reverse peak and is capable of giving 5 milliamp continuously or 20 milliamp for one hour. The shedded porcelain housings act as insulation for the high voltage terminals and the rectifier bank is isolated from earth by four pedestal insulators so that positive or negative D.C. can be obtained by connection to the top or bottom of the bank, the opposite end being earthed. The output from the charging unit is fed to the first stage of the condenser bank through a carbon disc charging-resistance of about 1 megohm. Contact is made to earth at the output side of this resistance by means of a movable rod, which makes contact when the transformer is de-energized and is automatically disconnected by a copper disc motor when the transformer is energized. This earthing device is shown in the earthed position on the right hand side of the illustration.

Condenser Bank

The main condenser bank consists of four columns, each made up of condensers and insulating members alternately. Externally, the oil-filled shedded porcelain shrouded condensers are indistinguishable from the insulating spacers. Referring to Fig. 1, the

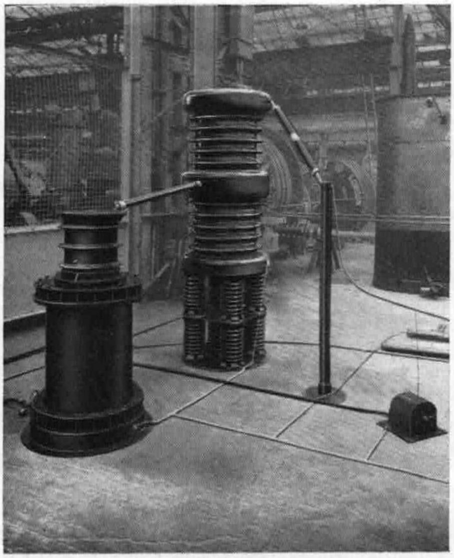

FIG. 2.
167 *kV D.C. Charging Unit.*

left hand front and back columns are identical and each consists of four condenser units and three spacer units erected vertically. Similarly, the right hand columns each consist of four spacer units and three condenser units. The front and back columns are permanently paralleled by the spark gap supports and it will be seen that the bolted connections between the individual units are surrounded by smooth sheet steel corona shields.

Each condenser unit has a capacity of 0·0875 μF. and, since two units are permanently in parallel per stage, the stage capacity is 0·175 μF. The total energy output with seven stages each energized at 167 kV in series is 17 kW/secs.

Charging of the seven stages is accomplished by means of a set of sloping resistors connecting the front columns together and a similar set connecting the two back columns together. Those in front are of high resistance and are used for charging only. The rear resistances, of lower value, are wire wound and, besides acting as charging resistances, also control the wave tail. Tappings are incorporated to facilitate wave tail control.

Discharging of the condenser bank is accomplished by means of hemispherical 150 mm. gaps supported horizontally midway between the front and back columns. The left hand hemispheres can be set at any position required and then remain fixed. The right hand hemispheres are connected by means of cam mechanisms through gearing to a vertical rod. This rod, clearly visible in Fig. 3, is made up of insulating members and the design is such as to allow a certain latitude in alignment. The rod is driven through gearing by a small motor at the base of the generator. This motor also operates a Selsyn unit which, with a similar unit on the control desk, permits of remote indication of the gap setting.

Small damping resistances are inserted in the majority of the gap circuits which also serve as part of the wave front control. The gaps are arranged vertically so that they can " see " one another, the lower gaps irradiating those above. This helps in achieving positive firing of the generator. Connection from the condenser bank to the sample is effected by means of a wire wound resistance which, together with the damping resistances already referred to, controls the wave front of the impulse.

Capacity Potential-Divider

The capacity potential-divider visible in the foreground in Fig. 1 is made up of two high voltage condenser units each capable of withstanding 600 kVp. and having a capacity of approximately 60 pf. These units in series form the high voltage arm of the divider and are mounted on a steel base provided with rollers for mobility. In the base is mounted the low voltage element of the divider together with the recording-cable matching

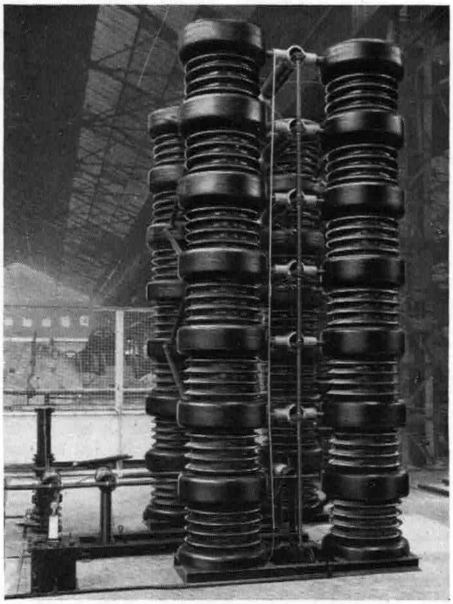

FIG. 3.
1 200 000 *kV Impulse Plant Main Condenser Bank Showing Spark Gap Drive.*

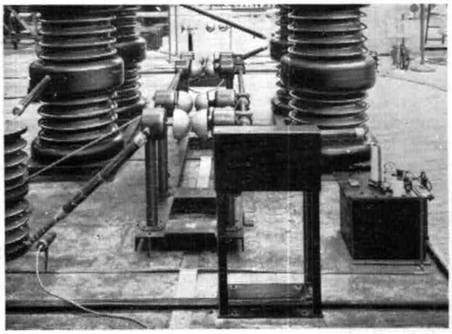

FIG. 4.

1 200 000 *kV Impulse Plant Auxiliary Tripping Mechanism.*

resistor. Special care has been taken to ensure that the low voltage capacitor is adequately screened and from this point the recording cable of low capacity is taken to the high speed continuously evacuated cathode ray oscillograph by the most direct route.

Tripping Mechanism

The tripping mechanism for the main condenser bank consists of two three-electrode gaps, two condensers with associated stabilizing resistors and a tripping transformer. Figs. 4 and 5 are two views of the base of the main condenser bank showing the various components.

The double three-electrode gap is visible in the centre of Fig. 4 and consists of four hemispherical two-electrode gaps, two of the hemispheres being bonded in each case. The gaps are arranged in this manner for the purpose of irradiation to improve operation. All electrodes are mounted on insulating members on a welded channel iron base, and are driven by cam mechanisms ganged together to a motor driven insulated shaft. The motor drive together with a Selsyn unit for remote indication of the gap settings, is housed in the metal box in the foreground. This drive is identical with that for the main gaps.

On the right is the tripping transformer which injects a voltage of up to 30 kV into the common electrode of the first two gaps when energized and this initiates operation of the generator. This transformer is of special design to have a suitable wave form and damping windings are incorporated to ensure that the injected voltage is not oscillatory. On the left of Fig. 4 will be noticed two porcelain clad condensers mounted vertically, which are connected across the two three-electrode gaps so that the potential of the various electrodes are maintained at the correct values for positive operation in sequence immediately the balance is upset by the injected voltage from the tripping transformer. In order to maintain the voltage on the condensers in the correct ratio in spite of the vertical mounting, two porcelain clad resistors are connected across the combination. These resistors are evident in the foreground in Fig. 5. The resistors serve another purpose which is dealt with below. From the left hand hemisphere to the base of the lower condenser is connected a tapped wire wound resistor from which is taken the initiating cable for the cathode ray oscillograph. The way in which the tripping mechanism functions in ensuring positive and repeatable operation of the whole plant will be described in Part IV of this series.

Voltage Measurement

The importance of accurate voltage measurement both for plant operation and comparison of test values is self evident. Instruments are provided for measuring the low voltage input to the charging unit and tripping transformer in parallel.

In order to measure the voltage on the first stage, use is made of the resistors which are connected in parallel with the condensers joining part of the tripping mechanism. The resistors are oil-immersed, porcelain clad, 100 kV units of 200 megohms each and

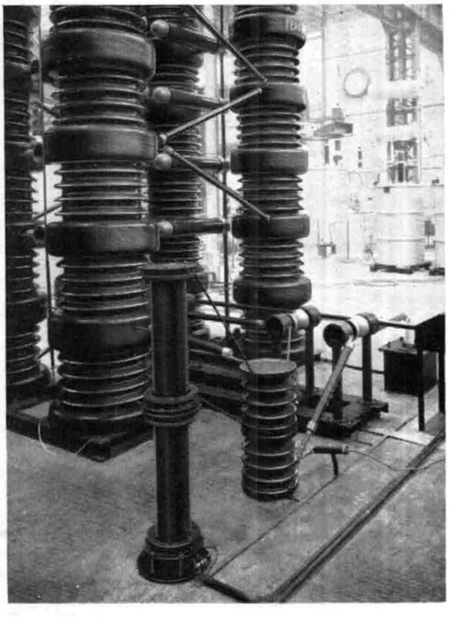

FIG. 5.

1 200 000 *kV Impulse Plant Auxiliary Tripping Mechanism. Showing Stabilising Resistors.*

together give a total of 400 megohms. The lower end of the two in series is connected to earth through a D.C. micro-ammeter calibrated to read mean kV and protected by the usual protective devices.

For measuring the output peak voltage two 50 cm. spheres are available which operate satisfactorily up to a voltage of 500 kVp. and can be used directly with four of the seven stages at full excitation. Up to this value the sphere gap is used to calibrate the capacity potential-divider and oscillograph and as the calibration is linear the peak voltage of the output wave can be obtained from the oscillogram for higher voltages provided the necessary precautions are taken.

Earthing

Since the impulse generator necessarily produces a unidirectional voltage of short duration by condenser discharge, efficient earthing is vital from the point of view of extraneous discharges and to provide complete safety for operating personnel.

There are two pits containing copper earth plates situated in front of and behind the main condenser bank, the earth plates being connected by 3″ × ⅛″ copper strip. From this main earth bar, smaller strips lead away to the other components of the plant and are clearly visible in Figs. 2 and 4. The junctions of all earthing strips are riveted and soft soldered to give efficient connections.

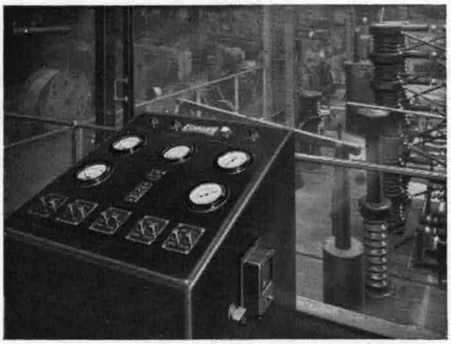

FIG. 6.

1 200 000 *kV Impulse Plant Control Desk.*

Reference has already been made to the motor operated automatic earth device shown in Fig. 2, but in addition two earthing rods with insulated handles are provided for manual operation which hook on to the spark gap supports on each side of the condenser bank. One of these rods is in position to the left of the gap operating rod in Fig. 3.

Control

The impulse generator is controlled from a control pedestal situated in the control room overlooking the test-floor. The control pedestal is shown in Fig. 6 with the impulse plant in the background.

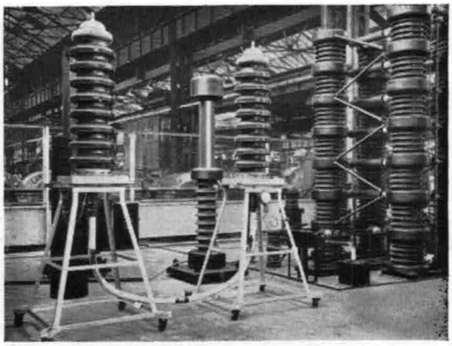

FIG. 7.

1 200 000 *kV Impulse Plant Layout for Testing 132 kV Cable Sample.*

At the top of the desk are the usual indicator lamps. In the centre are the indicating instruments, those on the left giving the low voltage input, the centre one reading mean stage kV and those on the right, driven by Selsyns underneath, indicating the settings of the main and auxiliary gaps respectively. Below are the five sets of push buttons, operating the isolator, main contactor, moving coil regulator, and the two gap motors respectively. The push-button in the centre is the final control which energizes the tripping transformer and causes the generator to operate.

On the side of the cabinet is a Castell switch and a relay. The Castell switch is a simple method of ensuring that the plant cannot be energized unless the input switchgear cubicle and the control pedestal are closed and locked. The relay is a high speed hand reset instrument which is incorporated as part of the normal light-ray protective equipment of the laboratory. Since the area is served by an overhead crane, an additional electrical interlock on the crane supply is fitted in the supply cubicle to de-energize the crane when it nears the impulse plant, if the latter is in operation.

The general layout of the plant when used for cable testing is shown in Fig. 7. The sample in this case is a short length of 132 kV gas cushion cable fitted with sealing ends approximately 6 feet long. The dimensions of the plant can be appreciated when it is realised that the metal screen in the background is 10 feet in height.

Reference has been made in the foregoing to the high speed continuously evacuated cathode-ray oscillograph and a description of this instrument will be given in Part III of this series.

Safe Loadings for Wood Poles

Can the Natural Tree be used as a Standard Reference?

By G. T. GARWOOD, B.Sc., A.M.Inst. C.E., M.I.E.E.

POLITICS apart, a really sound and economical system of light H.V. line construction offers farmers and other back-area rural dwellers one of the best possible guarantees of cheap and reliable electricity supplies in the years to come ; and as the cost of lines is so largely tied up with permissible pole loadings, it is obvious that we cannot afford unnecessary factors of safety. The recent relaxations have, nevertheless, given rise to some misgivings, which are by no means confined to ultra-conservative quarters. Nor, indeed, are they without substance. Thus, according to the previous regulations (E1.C.53—Revised), H.V. line poles were required to have a factor of safety of 3·5 when subjected to a wind pressure of 8 lb. per square foot, the conductors being coated with ice to a radial thickness of ⅜ inch. Now, according to the 1942 Regulations for light H.V. lines, the factor of safety of the pole is reduced, in certain circumstances, to 2·5, whilst the wind loading is changed to 16 lb. per square foot acting on the bare conductors only.

It is obvious, in the case of the smaller conductors, that the new assumed loading is less onerous than the old, and since climatic conditions remain unaffected, it is argued that the real reduction in factor of safety is greater than is implied by the ratio of 3·5 to 2·5.

The argument may be pressed more closely, as follows. If, in the case of a given line, the new regulations call for a pole of, say, only one half the ultimate transverse strength required to satisfy the old regulations, then the true factor of safety is only one half of what it was before, contrary nominal values notwithstanding.

The effect of the new regulations on the true factor of safety, so regarded, may be seen from a typical example, as follows.

(1) Consider a line with a 300 ft. span of 3 × ·025 (3/·104) conductor in horizontal formation and without continuous earthwire erected to the old regulations, E1.C.53 (Revised), i.e., ⅜ inch ice and 8 lb./ft.^{2} wind with a F.S. for the pole of 3·5. With normal assumptions, this requires a pole diameter of about 10·5 inches at the point of greatest bending moment.

(2) Now consider the same line erected to the 1942 Relaxed Regulations, i.e., no ice and 16 lb. wind with a F.S. for the pole of 2·5. Here the corresponding diameter works out at nearly 6·5 inches, so that the minimum of 7 inches would apply.

The ratio of pole strengths in these two cases would be directly as the cubes of the diameters and inversely as the effective lengths of the cantilevers, which works out at about 3 : 8.

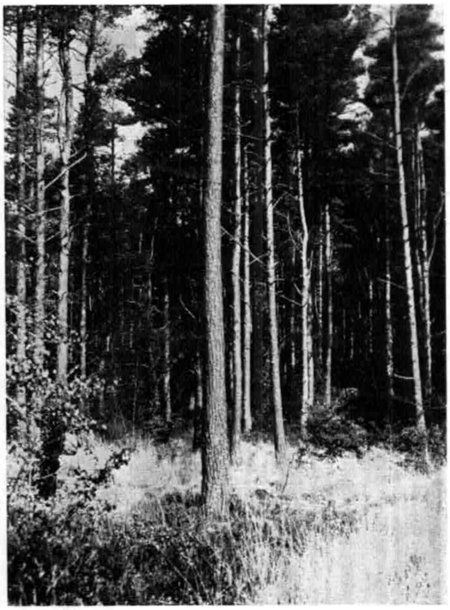

FIG. 1—*Scots firs with low "form-factor."*

Owing to the mutual shelter provided by these trees their boles are substantially cylindrical.

So, runs the argument, if the original factor of safety was 3·5, the true factor of safety under the revised Regulations is only 3/8ths of 3·5, or 1·3, say. For a substance such as wood, which is subject to flaws and decay, this certainly seems to be cutting very near the knuckle.

But there is also a flaw in the argument, and it lies in the assumption, or implied assumption, that there is something fundamentally more " true " about the original assumed loading conditions than there is about the revised ones. This, of course, is not the case : instead of saying that the original

F.S. was 3·5 in the case worked out above, and that the new F.S. is really only 1·3, it would be equally correct to say that the new F.S. is 2·5 and that the original F.S. was really $2{\cdot}5 \div \frac{3}{8}$, or about 7.

In these circumstances, discussion of maximum permissible pole loadings usually settles down into a debate on climatic conditions—whether the combination represented by *a* inches of ice plus *b* lbs. of wind at a temperature of *c* corresponds more closely to actual conditions than some other combination. This is an extremely unsatisfactory approach to the problem, and one that is embarrassed by the consideration that, even in sheltered inland localities, ice greatly in excess of $\frac{3}{8}$ inch and winds substantially in excess of 70 m.p.h. (i.e., 16 lb. per square foot) are usually on record.

In these circumstances, it is rather remarkable that nobody* seems to have thought of appealing to Nature for a verdict. Nature, after all, has been using wood poles in quite a big way and for quite a long time—and, moreover, for the performance of essentially the same mechanical duties as are required of overhead line poles. The mechanical functions of the trunk of a tree are, indeed, essentially the same as those of the line pole into which it may ultimately be converted. In both cases the compressive load is usually but very moderate, the strength of the structure being principally taxed to withstand the transverse bending moments due to wind loading. Also the same winds blow upon both tree and pole.

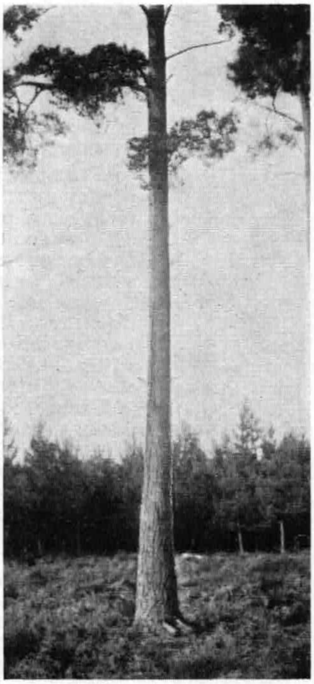

FIG. 2—*A case of high "form-factor."*

Here the tree is isolated and exposed to winds, and has developed a heavy conical bole for the resistance of transverse bending moments.

Now it is obviously a prime condition of survival for any organic structure that it shall be sufficiently strong to withstand the mechanical forces likely to be imposed upon it—at least before the onset of decay—and no tree species, the normal individuals of which failed to comply with this fundamental requirement, could possibly have survived.

It is, therefore, submitted as an axiom that trees are *at least* sufficiently strong to withstand the wind loadings of their normal habitat, and that if the ratio of strength to loading employed by Nature could only be evaluated, it would provide a fundamental criterion for the loading of line poles.

There are, however, many vague points about this axiom which require clearing up before the argument can be carried any further. In the first place, in referring to "trees" in general terms the writer really has in mind the coniferous trees hitherto used in this country for line poles, principally the red fir, *Pinus Sylvestris*. For the rest, the practical fact to which it is required to give expression is that healthy trees of this species *never* break under the influence of wind. "Never" is a big word, but the writer believes it can be justified for all practical purposes. He has himself lived for many years in the New Forest where there must be hundreds of thousands, if not millions, of these trees, some planted, some self sown ; some sheltered and some in high and windy situations. Yet, although he has recreated freely in the New Forest and has motored, tramped, and ridden over every part of it, he has never seen a healthy tree *broken* by the wind ; and the forestry experts and old and experienced woodmen whom he has questioned, unhesitatingly say the same. It is true that when the felling of a dense stand exposes isolated survivors to winds to which they have never been accustomed, they fall over like ninepins at the first serious puff, but the failure is always in the root structure and not in the bole.

There is really nothing extraordinary about this immunity from breakage in view of the characteristics of these trees, which, like those of any other organism, are partly inherited and partly acquired.

The inherited strength of the tree sums up, so to speak, the general experience of its countless ancestors, and even if a tree could be grown in an artificially windless environment, it would undoubtedly grow to a diameter sufficient to withstand transverse loads of which it would have had no experience. In addition to this inherited strength, the young sapling also possesses the capacity to modify its structure according to its own loading experience. Thus, in the case of trees grown in the middle of a dense plantation, where they really have very little experience of wind load, it will be found that the boles closely approach a cylindrical form, or, in forestry parlance, they have a " form factor " closely approaching unity. But in the case of trees in exposed situations, it will be noticed that they have added a considerable amount of wood to the lower portion of the trunk for the resistance of transverse bending moments, as a result of which they display a much higher form factor (see Figs. 1 and 2). The root structure also is adequately extended.

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*The author would welcome evidence refuting this deliberately provocative statement.

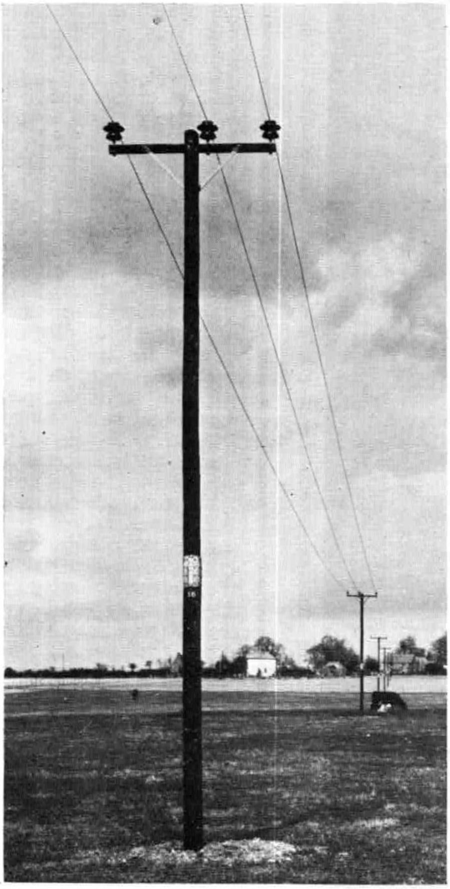


FIG. 3—*Effect of wind on a light* 11*kV line designed to the relaxed regulations.*

When this photograph was taken, there was a transverse wind of about Beaufort 8—9 (30—40 *m.p.h.) but there was no visible deflection of the poles. Under a similar wind, the crown of the tree shown in Fig.* 2 *deflects about* 4—6 *inches.*

As a result of this power of adaptation, and of Nature's well-known reluctance to build up working tissue in excess of practical requirements, the writer would expect to find a high degree of consistency in the ratio of strength/loading as between different trees of the same species, it being understood, of course, that only healthy specimens, in their prime, and, for present purposes, all growing in the same exposed locality, are under consideration.

Perhaps the most obvious suggestion for obtaining the required information would be to select a number of suitable trees in an exposed locality and to observe their deflections under high winds. Then, by applying artificial transverse loads under calm conditions, and measuring the corresponding deflections, it appears that the strength to loading ratio could be calculated. The writer, indeed, tried to do this, but without success ; for, apart from the over-riding difficulty of being on the spot when suitable winds were blowing, there were other difficulties, the chief of which was the impossibility of substituting a single artificial load equivalent to the distributed load due to the wind. In other words, the maximum bending moment for a given deflection is not the same for a distributed load as it is for a concentrated load ; and when the distribution of the load is unknown, the relationship of the maximum bending-moments is, strictly speaking, incalculable.

This particular difficulty could be overcome by observing and analyzing the curvature of the axes of the tree trunks under loading conditions—a method which suggests a mechanical observer, stationed, say, at a point on the coast exposed to the prevailing winds, and directed to the observation of some suitable trees during the equinoctial gales. The observer could consist of a kinematographic or other camera, including in its field of view, the trees concerned, a plumb-line or its equivalent, and a hot-wire anemometer scale. The trees would need to have a straight and vertical white line struck down their sides under dead calm conditions, such as might be provided by a plumb-line of surgical tape, pressed on to the trunk. The camera could be arranged to operate automatically on the occurrence of a sustained blast of the minimum desired velocity ; and a subsequent analysis of the curvatures of the axes of the

(*Concluded on page* 267)

Rural Overhead Lines

Some Notes on Increasing their Electrical Capacity

By J. E. STANTON

ELECTRICITY undertakings are concerned at the present time with the problem of load increase and the ability of their existing rural networks to cope with this increase. The problem is complicated by the following factors :—

(1) The rate of increase of load since the end of the War has been substantial. The extent of this increase is still problematical and estimates based on pre-war rates of increase are no certain guide because the restrictions imposed on domestic consumption and growth of connected load during the war years introduce unknown factors.

(2) In almost every case there have been radical changes in the locations of load centres due to war industries. It is certain that industries thus created will remain and the question of supplying power on a larger scale than during the War has now become an important one. Over and above all this, new and substantial building schemes have been commenced.

When these effects are considered with the fact that supply networks have, with the exception of direct supplies for war purposes, remained unaltered since the beginning of the war, it will be found that the load capacities of many E.H.T. mains are totally inadequate. Apart from the question of the size of the mains, there must be a greater tendency to ensure continuity of supplies by means either of duplication of mains or ring main networks.

It is inevitable that mains construction will be difficult for some time and to replace overhead lines by others or by underground cables will be a costly and lengthy job. The introduction of regulators provides a small increase in load capacity but their availability is restricted owing to the demand for apparatus of this nature. Again, regulators for rural overhead lines will have to be considered against other methods owing to the cost of the equipment, the capitalized cost of increased losses, and switchgear and maintenance costs.

With overhead systems, which comprise the principal method of transmission and distribution in rural areas, by the acceptance of the suggestions herein submitted, it will be found possible to effect a large increase in load capacity by re-stringing the lines with larger and higher conductivity conductors without serious alteration to the supporting structures.

A wide variety of types of rural overhead lines were erected just prior to the war with conductors of copper, galvanized steel, Copperweld, steel-cored copper, copper-cored steel, cadmium copper, etc., supported by wooden poles. These lines, operating at 11 000 V were, and still are, geographically correct and cover very satisfactorily the area of supply. Where they are of adequate capacity, supply undertakings can consider the question of extending spur lines to establish ring mains.

It is lines such as these that are potentially suitable for restringing.

In approaching the problem, it is desirable to appreciate the principal factors of mechanical design and the Electricity Commissioners Regulations governing the design, as given in ELC.53 as well as the relaxations contained in their memorandum, dated 18th September, 1942.

The writer suggests that the Electricity Commission should approve of a small modification to the regulations to enable existing small-section conductors to be replaced by conductors of larger section.

The relaxations set out in their letter of 16th Sept., 1942 and subsequently incorporated in B.S.1320—1946, were very sound and most gratefully received, but they deal with new overhead lines, with conductors up to 0·05 sq. in. section. In connection with supports, the relaxations provide :—

(i) For conductors consisting of imported poles, a factor of safety of 2·5 in lieu of 3·5 formerly prescribed.

(ii) That supports of home-grown wood poles may be used with a factor of safety of 3·5 for lines of a temporary character, or if of less importance, the factor of safety may be 2·5 in lieu of 3·5. A higher factor of safety on home-grown poles was decided upon mainly because experience with their use had, at the time amendments were frames, not been of sufficient duration to enable a close assessment of their life to be made. The five years or so of further experience gained may be very useful in revising assessments of the probable life of home-grown poles, and consequently, the factor of safety.

(iii) For reinforced concrete supports of approved design a factor of safety of not less than 2 in lieu of 3·5.

(iv) When calculating the size of the support, the wind pressure on the support may be left out of account, subject, however, to the loading on the conductors being calculated on the basis set out in paragraph 3, B.S. 1320—1946 ; referred to later on.

(v) The minimum size in the case of wood poles to be not less than 7ins. in diameter at a point 5ft. from the butt end.

In the present situation of wood-pole supplies and line materials generally, it is doubtful if the temporary lines erected to a factor of safety of 2·5 on the supports of home grown timber will be removed for some years. It is therefore suggested that the factor of safety for imported pine-wood poles on existing overhead lines could be reduced from 3·5 to 3. These poles were first-class material with a long life and are probably now far stronger with a factor of safety of 3 than home grown timber with 2·5. Certainly the period of service already performed by the poles should be taken into consideration and it is suggested that this proposal should only apply to supports erected since, say, 1930.

It is not suggested that the wind load on the supports should be left out of account, this being at the previous values ; only that the factor of safety should be reduced to 3.

The result of this reduction of the factor of safety on poles would be that the 0·025 sq. in. cadmium copper, 7/12 s.w.g. galvanized steel, the Copperweld, and various other conductors could immediately be replaced by 0·1 sq. in. copper conductors. Additional stays may be necessary at terminal poles and possibly stronger terminal steelwork would be required, but these are small items. The main feature is that the poles are erected on site and the transforming points are established. All way-leave difficulties have been overcome years ago, all claims, G.P.O. and railway crossings, tree cutting, and the many other difficulties of line erection are things of the past. The spur lines can be lengthened and secondary rings established. For the time being the protection could remain as at present and if it was desired to keep the ring closed this could be done through H.R.C. balancing-fuses or oil circuit-breakers fitted with graded earth leakage protection. In either case, in the event of a fault on either side of the mid point, one half of the ring would be isolated. It may be necessary to instal a ring main controller at certain points, although in many cases this has already been done to facilitate maintenance.

Referring again to the Commissioners relaxations of 16th September, 1942, paragraph 5 (b) which is embodied in paragraph 3 of B.S. 1320—1946, this provides :—

> A factor of safety of not less than 2·5 for line conductors based on the breaking load and calculated on the assumption (i), that the line conductors are a temperature of 22° F., but are without ice loading ; and (ii) that the wind is exerting a pressure equivalent to 16 lbs. per square foot calculated on the whole of the projected area of the conductor.

This refers only to conductors up to 0·5 sq. in. copper or to copper alloy or composite conductors up to 0·04 sq. in. copper equivalent and not larger than 7/14 s.w.g. steel conductor.

It is not suggested that this design basis should be allowed for conductors up to 0·1 sq. in., as dangerous tensions would be involved, necessitating additional costs in reinforcing steelwork, stays, etc. It is sufficient therefore to consider up to 0·05 sq. in. copper, for we are not at the moment concerned with sags and tensions, but with what is the largest conductor which can be erected on supports of a certain size. If the factor of safety of the line conductors is reduced it certainly helps, but it is considered more pertinent to deal with the supports.

The Commissioner's relaxations of 16th September, 1942, allow for conductors of ·05 sq. in. upwards to be erected with a minimum height of 17 ft. at a temperature of 122° F. It is therefore suggested that the factor of safety of 2 for conductors of ·05 sq. in. upwards remains as at present with ice loading of ⅜ in. thickness. The result is a reasonable tension that can be secured with standard steelwork and stays which involves no difficulties in erection or reinforcement.

If the Electricity Commissioners would agree to the modification suggested earlier, namely that the factor of safety on imported pine wood poles at present erected and supporting overhead line conductors be 3 in lieu of 3·5, the problem of dealing with increased loads immediately would be materially assisted.

To carry the proposals a little further, to agree to this amendment for new lines and also for conductors upwards of ·05 sq. in. section where imported pinewood poles are used and where the factor of safety on the conductors remains the same as hitherto, would assist in reducing the costs.

No involved calculations would be necessary for changing a small-section overhead conductor for a larger one. The pole size is known, and the breaking-load can be obtained from pole tables by dividing by 3 and deducting the wind load on the pole (this can also be obtained by reference to pole tables). The maximum loading for the specific span is given and in most cases it will be found that a conductor as large as 0·1 sq. in. copper can be used.

Numerous existing overhead lines carry continuous earthing conductors. The relaxations in earthing on rural lines sanctioned by the Commissioners in 1942 and subsequently given a general statutory effect in

B.S. 1320—1946, the growing volume of satisfactory experience on unearthed 11 kV lines, and a very considerable volume of satisfactory experience with unearthed lines for higher voltages and having larger conductors than provided for by B.S. 1320, may give good cause to reconsider the wisdom of retaining the continuous earthing conductors.

The load capacity of a line having an earth conductor can be considerably increased by removing that conductor and utilizing the strength of the poles to carry larger load-transmitting conductors.

It would seem that there is little objection to this procedure for light rural lines provided that the conductors do not exceed 0·05 sq. in. copper after the change, because the lines would conform with B.S. 1320. For larger lines, however, the matter is one for the Electricity Commissioners' consideration and approval.

Some years ago solid conductors were largely used up to 00 s.w.g. (·095 sq. in. section and ·374 in. diameter). Breakages may have occurred although the writer cannot call to mind any particular failures, but this could be overcome by design of suitable fittings. Perhaps we may again have to think along these lines to assist in obtaining materials cheaply and quickly.

A few examples of the possibilities of increasing conductor areas by the suggestions which have been advanced are given in the table. It will be seen that in most cases it is not necessary to take advantage of the permissible 17 ft. ground clearance. The examples allow for the poles to be 6 ft. in the ground with the exception of the 32 ft. ones, and for the lower conductors to be at a point 2 ft. below the top of the pole. In all cases the figures are based on a span length of 400 ft.

H.T. Lines already erected to Old Regulations
($\frac{3}{8}$″ *ice loading, F. of S. on poles 3·5*).
(*F. of S. for conductors 2. Based on 400′ span.*)

Details if Conductor changed for 0.1 sq. in. (7/.136) Stranded Copper. F. of S. on Poles 3.

Type of Conductor.	Sag at 122°	Pole Height and Size.	Safe load on pole after deducting wind load on pole.	Conductor wind load. lbs. per ft.	Total wind load on 3 conductors 400′ span.	Safe load on pole F. of S. 3 after deducting wind load on pole.	Wind load 0·1 copper 3 wires 400′ span.	Sag at 122°	Ground Clearance.
7/12 Steel	4·28′	32′ × 11″	876	0·708	849	1 037	926	7′	18′
7/14 Steel	7·92′	36′ × 11½″	884	0·660	792	1 049	926	7′	21′
7/12 Copper Cored Steel ...	4·98′	33′ × 11″	876	0·708	849	1 037	926	7′	18′
0·025 Steel Cored Copper 6/0 ·073C—1/0·073S ...	9·75′	38′ × 11½″	811	0·646	775	965	926	7′	23′
7/12 S.W.G. Copperweld ...	4·15′	32′ × 11″	876	0·708	849	1 037	926	7′	18′
0·04 Steel Cored Copper 6/0·092C—1/0·092S ...	5·75′	34′ × 11″	836	0·684	820	991	926	7′	19′
0·025 (3/·112) Cad. Copper ...	9·63′	38′ × 11½″	811	0·661	793	965	926	7′	23′
0·04 (3/·141) Cad. Copper ...	6·56′	35′ × 11½″	923	0·703	843	1 094	926	7′	20′
0·04 Steel Cored Copper Segmental	7·76′	35′ × 11″	797	0·659	790	948	926	7′	20′

The President, accompanied by Mrs. Pickles, interested in the 132 *kV. Gas Cushion Cable exhibit on the C.M.A. Stand. Mr. C. Balle provides the answers.*

paper on "Recent Developments in Power Station Practice."

Mr. Lawton, in his opening remarks, recalled the classic paper on Power Stations presented to the Association by Mr. Lamb and Mr. Baumann in 1938, at a time when the impending war was but a rumour, and the Weir and McGowan Reports were but signposts on the path to the nationalization of the Electric Supply Industry. He devoted his attention to the remarkable changes that have occurred since that paper was delivered, many of these changes being largely influenced by the impact and stress of war conditions.

Surveying the scene, he pointed out that the growth of our national peak load from 1938 to 1945, has increased by 33%, reaching nearly 9 000 M.W., and the units sent out have increased by 60%, resulting in an increase in load factor from 36·8% to 43·8%. Notwithstanding the cessation of hostilities and neglecting load shedding, this high load factor is being maintained.

During this period the average overall power station efficiency has remained practically constant, due to the deterioration in the calorific value of coal supplied of about 7%, and the large proportion of obsolete plant remaining in service.

Mrs. J. W. Simpson (left) has a joke with the President, whilst Mrs. Pickles smilingly greets Mr. E. E. Hoadley, C.B.E. (Maidstone).,

The highest yearly station load factor has reached 88·28%, and the lowest number of men employed for operation and maintenance 1·3 per 1 000 kW of maximum demand.

Mr. Lawton set out comparisons of British and American power station practice, and in an interesting section dealing with High Voltage Cables remarked that there is ample justification for a paper to be written exclusively on the arrangement of power station cables. However, he confined himself to a brief reference to impregnated pressure cables now being used for voltages of 33 kV and above.

Direct generation at 33 kV has brought high voltage cables into the power station. Many stations step up from generation voltage to 132 kV, thus requiring underground cables working at this pressure to be laid between the transformer and the switching station. The oil-filled cable was successfully used before 1938, but the impregnated pressure cable has since been introduced. The use of cables of this type it is claimed reduces fire risks and increases the rating of circuits.

Mr. E. E. Hoadley, C.B.E., (Maidstone), looks on approvingly as the President places his contribution in the E.I.B.A. outstretched hand.

In the space at our disposal no adequate report of this very informative paper can be given, but the author's views on the possible development of atomic energy plant, form an appropriate conclusion to this brief summary. After reviewing the latest information available in America as well as in this country, he stated that atomic energy for electrical generation is still in the experimental stage, and until other elements more abundant and cheaper than uranium are found to be successful for this purpose, the present methods of electrical generation are likely to prevail.

The Tuesday evening function was the Reception by the Mayor and Mayoress of Bournemouth (Councillor J. W. Moore, J.P., and Mrs. Moore). Dancing followed, with hundreds of happy guests joining in with the high spirits so typical of such occasions.

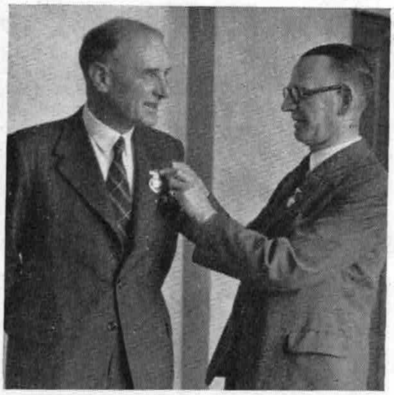
In accordance with custom, Wednesday was kept free of formal gatherings, and delegates found relaxation in visiting neighbouring places of interest, or in local recreations.

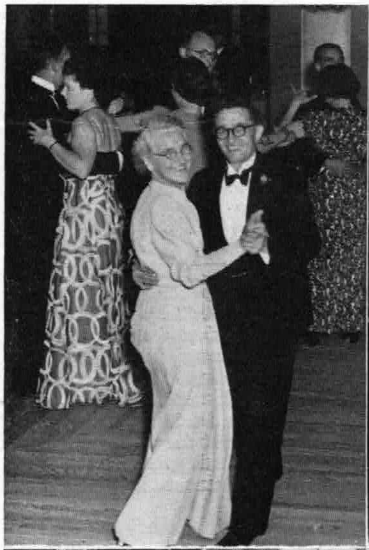
Caught by the Camera at the Convention

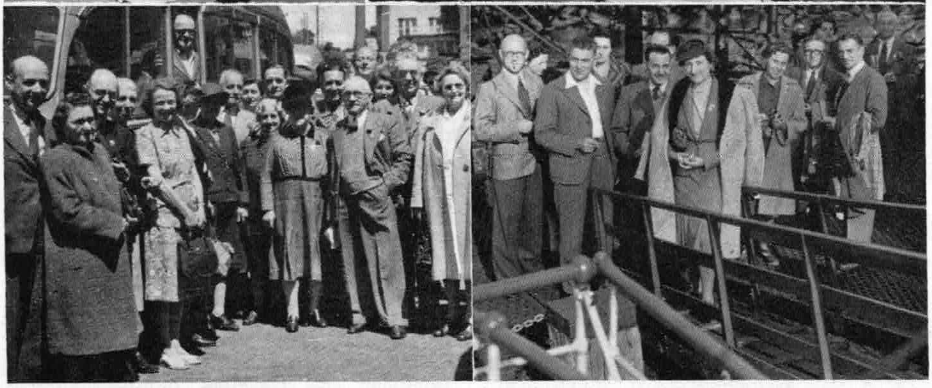
(On right) Mr. J. W. Simpson (Secretary), pins on the President's badge.

(Below left) Mr. G. W. Ablitt (East Ham) in happy partnership with the Mayoress of East Ham.

(Below right) At the Presidential Reception, Mr. G. C. Morley New, Ald. G. B. Brooks, O.B.E., Mr. R. A. S. Thwaites, Ald. Sir Wm. Walker, and their ladies in a friendly circle.





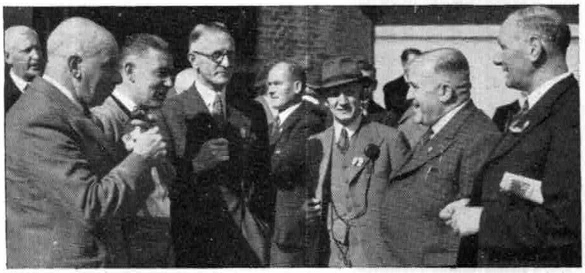


Trippers set off on land and sea to make the most of the glorious Convention weather.

Discussion Groups at Bournemouth

(Top. l. to r.)
Messrs. S. J. C. Ellis (Canterbury), Edwards (C.M.A.), E. B. Palmer (Leek), and C. Balle (C.M.A.), R. K. Jenkins (Workington), F. C. Horsford (Henley's), D. C. Thompson, B.Sc. (Walton and Weybridge), G. H. Squire (Henley's), W. B. Hayden (Epsom and Ewell), on the C.M.A. stand.

(Middle)
A London contingent (l. to r.):—Mr. W. C. Parker (Fulham), Coun. W. Hebden, J.P. (Shoreditch), Mr. R. H. Rawll (Shoreditch), Coun. A. German (Woolwich), Coun. J. W. Perotti, J.P. (Fulham), and Coun. J. O'Connor, J.P (Stepney), listen while His Worship the Mayor of Stepney makes a point.



(Bottom)
Outside the Pavilion (l. to r.):—Messrs. R. K. Jenkins (Workington), N. T. Smith (Warrington), W. H. Warhurst, LL.B., Coun. H. Preece Wolverhampton), Coun. J. Hopwood and Mr. A. Goward (Accrington), and His Worship the Mayor of Workington.

With Thursday came the return to the more serious side, the Third Session starting with a paper on "The Law Relating to Electricity Supply," presented by Mr. R. Birt, B.Sc., F.C.I.S., A.M.I.C.E., M.I.E.E., A.M.I.Mech.E. Mr. Birt, who is the Borough Electrical Engineer and Manager of Ealing, presented his exposition of a very complex subject with particular skill, dividing his paper into two sections, the first historical, and the second dealing with the alterations to the law relating to electricity supply resulting from the provisions of the Electricity Bill, 1947.

Today the general law relating to Electricity Supply is contained in no fewer than fourteen public general Acts of Parliament and in addition to these there are over two hundred Private Acts of Parliament and approximately five hundred provisional and special Orders dealing with the supply of electricity—a truly formidable total.

The principal guest at the Banquet and Ball held in the Pavilion Ballroom on the Thursday evening was Professor J. D. Cockcroft, C.B.E., F.R.S., the Director of the new Atomic Energy Research Establishment at Didcot.

In his speech, Dr. Cockcroft surveyed both the possibilities and the difficulties of the application of atomic energy in the generation of electricity. The principal problems to be solved are on the economic and possibly political sides rather than on the scientific side. While nuclear power has great potentialities and is worth great effort, there are perhaps 10 years of uncertainty as to what it will do.

Touching upon the inefficiency of our thermal use of coal, Dr. Cockcroft referred to the possibilities of the heat pump and in conclusion said that whatever changes result from the proposed reorganization of the electricity supply industry, it will continue to attract men of ability.

The Fourth Session opened with the Council Meeting preceeding the Ordinary General Meeting of the I.M.E.A., at which Mr. J. Eccles, B.Sc., M.Inst.C.E., M.I.E.E., M.I.Mech.E., of Liverpool, was invested with the Presidential Chain of Office, as successor to Mr. Pickles. Councillor J. Selwyn-Jones, J.P. was elected Vice-President.

So once again, the organizing genius of Mr. J. W. Simpson, the Secretary, and his hard-working staff, have provided Members of the Association and their friends with a profitable and enjoyable interlude in the normal round of duties.

Travelling Waves in Electric Power Cables

By A. W. STANNETT, B.Sc. (Eng.), Graduate I.E.E.

Henley Research Laboratories

IT has long been recognized that switching and atmospheric disturbances can set up voltage and current transients in an electrical power system. In the past, " surges " were often given as the cause of plant failures when no other reason could be found. Often, no doubt, this was unwittingly correct, for lack of knowledge was responsible for poor design as far as transients are concerned. In recent years, however, the subject has been widely studied by an ever-increasing number of engineers and is now on a very much firmer basis. The effects of a travelling wave on any circuit can be predicted mathematically with some certainty and equipment design can now be carried out to provide a suitable factor of safety from the surge point of view. Since such equipment is usually connected by cable to an overhead line it is essential to know how an incoming wave is affected by the cable.

Properties of a travelling wave

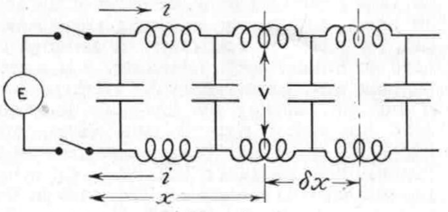


FIG. 1

Fig. 1 represents a line having uniformly distributed inductance, L per unit length and capacitance C per unit length, and negligible resistance and leakance, to which a source of e.m.f. E may be impressed. At the instant of closing the switch a voltage wave is impressed on the line having a vertical wavefront of peak value E and an infinite tail, and a current i flows to charge up the distributed capacitance of the line. After a small time interval, the conditions of current i and voltage V are established along an element of line δx. The voltage V is balanced by the back e.m.f. generated by the changing magnetic flux, which is produced by the current in the element of line. The flux built up is $(L\ \delta x)i$ and the back e.m.f. is the rate of build-up of flux $iL\ dx/dt$ therefore

$V=iLdx/dt=iLS$ . . . . . (1)

Where $S=dx/dt$ is the velocity of wave propagation.

The current i, carries a charge $i\ \delta t$ in time δt and as the capacitance of the length of line δx is $C\ \delta x$, its charge is $C\ V\ \delta x$.

Therefore $i\delta t= CV\delta x$

$i= VCdx/dt$

$i= VCS$ . . . . (2)

From (1) and (2) we get :—

$S=1/\sqrt{(LC)}$. . . . . . (3)

$i=V\sqrt{(C/L)}$ . . . . . (4)

Equation (4) is generally written $i=V/Z$, to correspond to Ohm's Law, where $Z=\sqrt{(L/C.)}$ This quantity is known as the surge resistance. As both L and C are expressed " per unit length," Z is independent of the length of line whether overhead or cable, whilst S has a definite value for a given line depending only on the paramaters L and C. For an overhead line, Z is of the order of 400—600 ohms ; for a cable 25—60 ohms. The velocity of wave propagation in an overhead line is approximately equal to the velocity of light, 186 000 miles per second. For a cable, the velocity is approximately 98 000 miles per second.

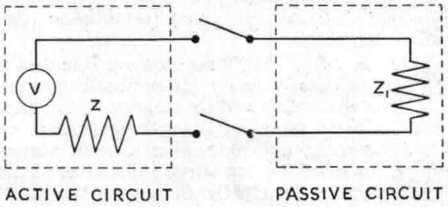


FIG. 2

Reflection and Transmission

When the surge reaches the open end of the line, the current i must vanish. This can only be caused by a current—i returning from the open end, back into the line, by convention, in a negative direction. As the ratio of V to i is always Z, a reflected voltage wave of V is produced when due regard is paid to the conventions of sign and direction. Thus the voltage at the open end is doubled.

Thévénin's theorem states that if a network has two terminals A and B between which is placed an impedance Z, the current through Z is given by $E/(Z+Zi)$ where E is the potential difference between A and B when Z is removed and Zi is the impedance of the network between A and B calculated by assuming that all the sources of voltage are replaced by impedances equal to their internal impedances. Should this line be connected to some other apparatus or cable, then by

Thévénin's theorem, the magnitude of the voltage surge that will be transmitted to that apparatus and also the magnitude of the voltage surge that will be reflected from the junction, can be obtained.

The junction of two lines having surge resistances of Z and Z_1 respectively and the voltage wave V travelling towards the junction can be represented by Fig. (2) as a circuit problem. The current in Z_1 will be given by dividing *Voltage at the switch when open, due to the active network* by $Z+Z_1=2V/(Z+Z_1)$

2V is used, because, with the switch open there will be a voltage doubling effect due to reflection, as already indicated. Hence, the voltage appearing across Z_1 will be given by

$$2VZ_1/(Z+Z_1)$$

This will be the magnitude of the voltage wave transmitted into the second line. The wave reflected back into the first line will be given by

$$2VZ_1/(Z+Z_1)-V=V(Z_1-Z)/(Z_1+Z)$$

The explanation given establishes the following points :—

1. A surge travelling along a line has a definite velocity determined by the capacitance and inductance of the line.
2. The ratio of the magnitudes of voltage and associated current surges is given by the surge resistance. This paramater has the dimension " ohms " and is dependent only upon the capacitance and inductance per unit length. As $Z=\sqrt{(L/C)}$, the surge resistance Z is independent of the length of line.
3. Should the line constants change suddenly, as happens at the junction of two dissimilar lines, at a tee junction, at the junction of line and cable or line, and at any other apparatus, the incident wave will be modified to give rise to two waves, one transmitted forward and the other reflected back.

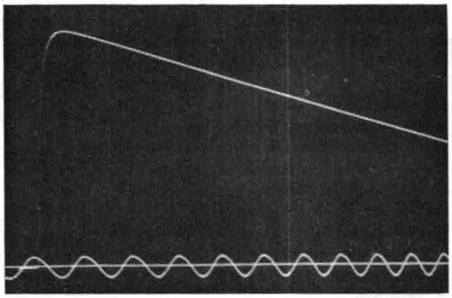
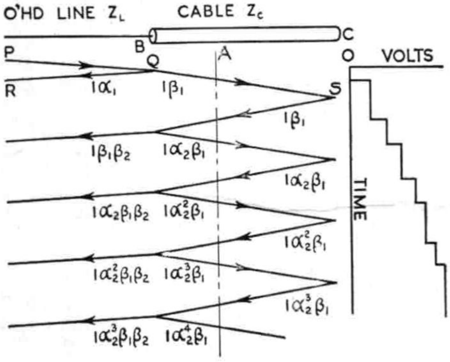


FIG. 3
Oscillogram of a typical 1/50 *wave.*
Timing oscillation, 0·2 *megacycles per second.*

Practical Examples

So far, we have considered a wave having a rectangular front and an infinite tail. Such a wave would occur if a constant voltage source were applied to a line. In practice, the waves to which transmission systems are subjected are not this ideal shape. They are of short duration having a wavefront of a microsecond or so, the tail dying down to half the peak value in a time of the order of 50 microseconds. Fig. 3 shows a typical 1/50 wave. The timing wave on this oscillogram is 0·2 megacycles per second. The nomenclature in connection with such waves is given in B.S. 923 (1940).



$$\alpha_1=\frac{Z_c-Z_L}{Z_c+Z_L} \qquad \beta_1=\frac{2Z_c}{Z_L+Z_c}$$

$$\alpha_2=\frac{Z_L-Z_c}{Z_L+Z_c} \qquad \beta_2=\frac{2Z_L}{Z_L+Z_c}$$

FIG. 4

Let us consider the case of a short length of cable connecting an overhead line and a transformer. The surge resistances of line (Z_L) and cable (Z_C) are of the order of 500 and 30 ohms respectively, whilst a transformer can, for most practical cases, be assumed to have an infinite surge resistance. If a rectangular wave travels along the overhead line, it will, on reaching the line-cable junction, split up giving rise to two waves, one $E(Z_C-Z_L)/(Z_C+Z_L)$ being reflected back into the line, the other $2EZ_C/(Z_L+Z_C)$ being transmitted into the cable. The wave in the cable will travel to the far end. Here it will be reflected so that it arrives back at the line-cable junction after a time T seconds, which is the time taken to travel twice the length of the cable. At the junction, this wave will, in turn, be split up into two, one wave being transmitted into the line, whilst another wave travels back along the cable. This process continues, each succeeding wave in the cable having a lower peak value than its originator.

The Bewley lattice diagram, Fig. (4) gives a picture of the effect of these repeated reflections. This diagram is a distance-time graph in which are plotted the main wave and all the reflected and transmitted waves. The transmission lines are drawn horizontally to a suitable length scale and the waves are plotted below to a vertical time scale, the origin being at the top. In the diagram, PQ represents the original wave of unit peak value travelling along the line with a velocity given by the slope of PQ. At the junction B two waves are originated, one, of peak value $2Z_C/Z_L+Z_C)$ travels in the cable and is represented by QS, the slope of QS, representing the velocity in the cable. The other wave, of peak value $(Z_C-Z_L)/(Z_C+Z_L)$ is reflected back into the line as given by QR. This procedure is repeated until all the required information is portrayed. As each successive generated wave is smaller than its originator by some factor such as

$$(Z_L-Z_C)/(Z_L+Z_C)$$

the waves soon have negligible peak values.

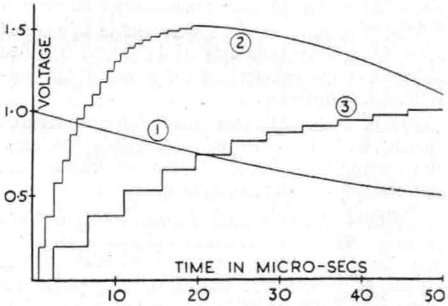


FIG. 5
(1) *Original curve*. (2) *Cable length* 125 *ft*.
(3) *Cable length* 300 *ft*.

With the aid of such a diagram it is possible to draw the wave shape that would be obtained by connecting a cathode ray oscillograph to a given point in the system. To the right of the lattice diagram the potential at point A is shown; it is obtained by projecting the incremental waves on the time scale.

For practical purposes it can be assumed that the incident wave has a vertical wavefront and drops to half-value in 50 microseconds, such a wave is expressed by $E\,\epsilon^{-0\cdot0138t}$. The effect of the application of such a wave will be similar to that described above except that the potential at the point B (Fig. 4) will be following the law $E\,\epsilon^{-0\cdot0138t}$ without the effect of the reflections and therefore will be decreasing as each successive reflected wave reaches B. With this effect taken into account, the potential of the point C can be expressed,

$$e=EQ(M^n-\epsilon^{-raT})/(M-\epsilon^{-aT})$$

where $M=(Z_1-Z_2)(Z_3-Z_2)/(Z_1+Z_2)(Z_3+Z_2)$

$Q=2Z_2Z_3/(Z_1+Z_2)(Z_3+Z_2)$

Z_1= surge resistance of the first line.

Z_2= surge resistance of the cable.

Z_3= surge resistance of the transformer.

$a=0\cdot0138$

T = time in microseconds for a wave to travel twice the length of the cable.

n = the number of reflections.

Fig. 5 shows the waveform at the point C for the application to the line of the incident wave given above, for cable lengths of 125 and 300 feet. A measured value of cable surge resistance of 28 ohms was used. This illustration shows that the real effect of the cable is to lengthen the wavefront to a degree depending upon the length of cable in circuit. It is also important to note that the peak value of the wave at the end of the shorter length of cable is approximately 50% greater than that of the incident wave. Figs. 6 and 7 show the variation of peak value and wavefront time for varying lengths of cable in circuit. It is thus demonstrated that far from acting as a surge absorber (as a short length of cable was once supposed to act), the voltage wave appearing at the far end of the cable and impressed upon the transformer will have a more severe effect than the original wave incident upon the line. It may be stated that for the conditions mentioned, the peak value of the wave at point C will have a peak value higher than that of the incident wave, unless the cable length exceeds about 200 yards.

Figs. 6 and 7 also show the peak values and wavefront times for the condition that $Z_3=500$ ohms. This is the case of the length of cable inserted in an overhead line and is included to illustrate the effect of terminal surge resistance.

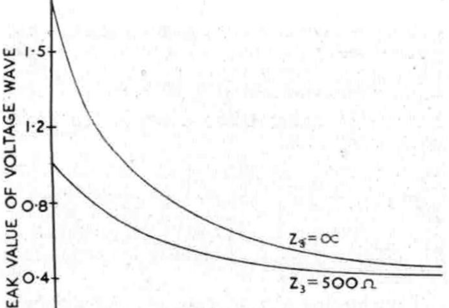


FIG. 6

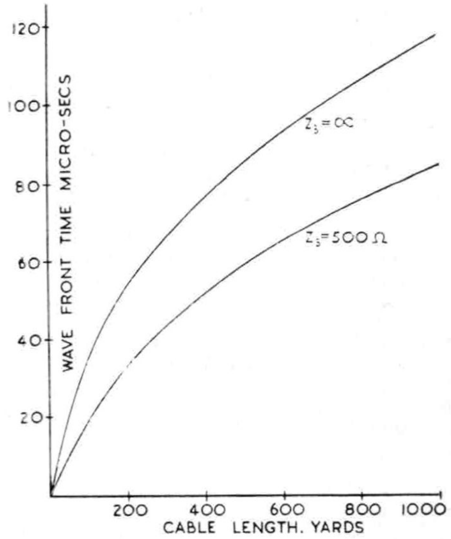


FIG. 7

Attenuation

Up to the present, attenuation has been ignored. The effect is very small unless extremely long lengths of cable or line are considered. To allow for the effect of resistance of the conductor, which is the main source of attenuation, it is necessary to modify the original differential equations.

For a wave of the form $E\epsilon^{-at}$, the expression for the waveshape after travelling a distance x along the cable is :—

$$e=E\left[\epsilon^{-at}-\frac{\sigma x}{\sqrt{\pi}}\left\{t^{-\frac{1}{2}}-\frac{1}{2}\cdot\frac{1}{3!}\cdot\sigma^2x^2t^{-\frac{3}{2}}\right.\right.$$
$$\left.\left.+\frac{1}{2}\cdot\frac{3}{2}\cdot\frac{1}{5!}\cdot\sigma^4x^4t^{-\frac{5}{2}}\ldots\ldots\right\}\right]$$
$$=E\left[\epsilon^{-at}-\operatorname{erf}\sigma x/2\sqrt{t}\right]$$

Erf $\sigma x/2\sqrt{t}$ is the " Error Function " and is expressed,

$$\operatorname{erf}\sigma x/2\sqrt{t}=2\pi^{-\frac{1}{2}}\int e^{-t^2}dt,$$

the integral being taken between the limits $\sigma x/2\sqrt{t}$ and zero.

As the name implies, this function was originally invented to aid in the study of Gauss' Law of Error. To save time in evaluating this integral, tables have been prepared, as the integral must be obtained by expanding e^{-t^2} into the series.

Considering the specific case of a single core cable with a wave travelling between core and sheath,

$$\sigma=\sqrt{(\rho_1\times10^{-9}/\pi)}\div d_1Z$$

where d_1 =outside diameter of lead sheath in cms.

ρ_1 =resistivity of lead sheath in ohm/cm³.

Z =Cable surge resistance in ohms.

Fig. 8 shows how the waveshape is altered after travelling distances of 1, 3 and 5 miles along the cable, obtained by using the expression given above.

It is seen that the peak value decreases slowly with the distance travelled, but that the wavefront time becomes finite and increases with distance travelled.

Where it is desired to deal with a wave having a finite wavefront initially, it is assumed that the wave starts as a vertically fronted wave, at a distance ahead of the point regarded as the starting point. By taking such an arbitrary origin, waves of the shape given by $E(\epsilon^{-at}-\epsilon^{-bt})$ where a and b are constants can be considered as more closely representing conditions in practice.

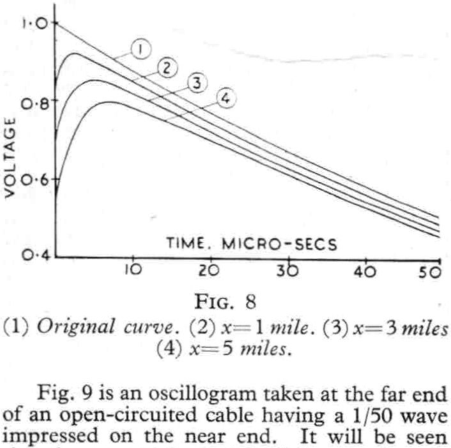


FIG. 8

(1) *Original curve*. (2) $x=1$ *mile*. (3) $x=3$ *miles* (4) $x=5$ *miles*.

Fig. 9 is an oscillogram taken at the far end of an open-circuited cable having a 1/50 wave impressed on the near end. It will be seen that the stepped formation of the wavefront is of the same type as that calculated for a 1/50 incident wave on a length of cable of 125 feet, open circuited, as shown in Fig. 5. In the calculated curve, the wavefront is made up of vertical and horizontal steps. In the practical case, the vertical components slope to the right due to the fact that the 1/50 wave has a finite front and the horizontal components are shown to droop due mainly to the phenomenon of attenuation as already discussed.

In the foregoing an attempt has been made to demonstrate how a given point in a transmission system can be affected by a wave incident upon the system at some other point. Only an outline of the method has been given, but sufficient has been said to show that the principle is applicable to any system, however complicated, provided the behaviour of

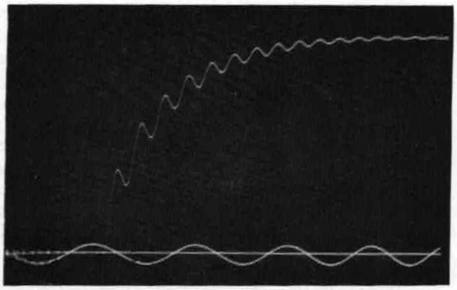


FIG. 9—*Oscillogram taken at the far end of an open-circuited cable with a* 1/50 *wave impressed on the near end.*
Timing oscillation, 1 *megacycle per second.*

the wave is traced step by step through the system. It will be apparent to the reader that as the complication of the system increases, the mathematics involved becomes extremely laborious.

(*Continued from page* 258)

tree trunks under winds of known strength, together with a record of deflections observed from the application of known loads, would, in theory, provide the data for calculating Nature's strength/loading ratio in the cases examined.

In practice, however, it is extremely doubtful whether the several radii of which the curvature of the axis of the loaded trunk is compounded could be analyzed from a small photographic negative.

Two more or less practical suggestions emerge from these considerations: firstly, observing deflections under wind loading and artificial loading respectively, and applying the latter at the *estimated* point which would give equivalent bending moment at the base of the trunk* ; and, secondly, applying a maximum fibre strain indicator to the bole of the tree, and associating its indications with those of a recording anemometer and with observations of the strain produced by artificial loads. This latter method has important potential merits, including that of being based most nearly on the observation of the fundamental quantity concerned, namely, maximum fibre stress.

Here, then, is the possibility of obtaining an oracular answer to the pole loading question, needing correction only for the superior modulus of rupture of seasoned as opposed to green timber, and providing a standard of reference at least as permanent as the British climate. Is it too much to hope that some interested person or organization with the necessary time and facilities may pursue the matter ?

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*This should not be difficult with the more bushy-headed trees.

Units and Dimensions

Part II

By G. W STUBBINGS, B.Sc., A.M.I.E.E.

NO great difficulties arise in the applications of dimensional theory to dynamics because of the close connection of all physical quantities arising in this science with the fundamental entities of mass, length and time. One minor ambiguity has already been pointed out, that, according to the conventional theory, dynamical quantities different in objective nature, can have the same dimensions. The identity of the dimensions of torque and work has been mentioned already and this seems to indicate a gap which vitiates the coherency of dimensional theory in the field of dynamics. We have already shown how simply the isochronism of linear vibrations can be proved by dimensional theory. No such proof is possible for torsional vibrations because, as the quantity, angle, according to conventional theory is dimensionless, the amplitude of a torsional vibration cannot enter into a dimensional equation. This gap, which limits the application of dimensional theory to the dynamics of rotation, can be filled up by assigning a fourth dimensional symbol to an angle. If this is done, the dimension, angle, enters into the formulæ for both torque and moment of inertia, and with this complication, the isochronism of torsional vibrations can easily be proved by a dimensional equation, when the control torque is proportional to the angular displacement. Without this complication, dimensional theory, even in dynamics, seems to be imperfect. It is true that any equation expressive of an objective condition must be dimensionally homogenous, but an equation in which quantities of similar dimensions but of different physical characters are added may be meaningless, objectively. The apparent imperfection of dimensional theory as applied to dynamics is, in the writer's experience, skated over very lightly in the text-books in which it is referred to, and no convincing explanation is given of the anomaly whereby identical dimensional formulæ are assigned to radically dissimilar quantities.

The application of dimensional theory to branches of physics other than dynamics leads to difficulties because of the recondite connection of the quantities involved with the fundamental entities of mass, length, and time. Because of this, statements about the dimensions of non-dynamical quantities in the text-books are not always consistent. This applies to the dimensions of thermal quantities. If the student refers to a standard classic, Watson's *Text Book of Physics* he will see that in working out the dimensions of thermal quantities, a fourth fundamental dimension is used, that of temperature. On the other hand, if he turns to a well-known reference book, *Whittaker's Electrical Engineer's Pocket Book*, he will find that the dimensions of thermal quantities are all given in terms of mass, length and time, the dimensions of temperature being those of the square of a velocity.

This dimensional formula for temperature is worked out in the following way. As energy of mechanical work is completely convertible into heat, a quantity of heat has the same dimensions as energy, ML^2/T^2. The quantity of heat absorbed by a body is the product of its mass, its temperature rise, and the specific heat of the material of which it consists. Now specific heat is a pure number and dimensionless, because it is merely the ratio of two quantities of heat which raise by equal amounts the temperature of the material of the body and an equal mass of water. We thus have the dimensional equation $ML^2/T^2 = M \times$ temperature, so that the dimensions of temperature are L^2/T^2. This conclusion seems to be supported on rational grounds, because, according to the kinetic theory of gases, temperature is proportional to the molecular kinetic energy per unit mass. It also has the authoritative sanction of Lanchester in his well known work, *Theory of Dimensions*.

Although at first sight the foregoing argument seems plausible, further consideration shows it to be fallacious. The product, mass by specific heat by temperature, gives a quantity of heat in thermal units, not in dynamical or energy units, and to convert thermal to dynamical units we have to multiply by a factor known as the mechanical equivalent of heat and usually denoted by the symbol, J. The nature of J can be understood by considering a comparable case.

The mass of a body in C.G.S. units is equal to its volume multiplied by its specific gravity, and this statement is like heat per degree of temperature is equal to mass multiplied by its specific heat, for specific heat and specific gravity are each dimensionless quantities. But the statement that mass is equal to the product of volume by specific gravity is true for a particular system of units only, one in which the mass of unit volume of water is unity ; in any other system the statement is incorrect, and the product of volume by specific gravity must be multiplied by the density of water to obtain mass. Thus, in the F.P.S. system of units mass in pounds is equal to the product of volume in cubic feet by specific gravity by 62·43, the mass in pounds of a cubic foot of water. Similarly, to obtain quantity of heat in dynamical measure per degree of temperature rise, the product of mass by specific heat must be multiplied by the specific thermal capacity of unit mass of water in the same system of units, or the heat in energy units required to raise the temperature of unit mass by unit amount. This latter factor is what is generally called the mechanical equivalent J ; actually it is a specific thermal property of a reference, substance, water, used in the definition of the thermal unit, which is analagous in its nature to the density of the reference substance, water, used in the definition of specific gravity.

The correct dimensional equation corresponding to that expressing heat in dynamical units is therefore $ML^2/T^2 = M \times J \times$ (temperature), so that, putting θ for the unknown dimensions of temperature, we have $J = L^2/T^2\theta$. The additional dimensional symbol for temperature therefore is essential, and it is not legitimate to assume that J is dimensionless, and so to infer that temperature has the dimensions L^2/T^2.

The dimensional formula for J shows how, being given a numerical value for this constant in any one system of units, we can calculate its value in any other system. Thus, taking J as 777·2 ft.-lbs. per pound per degree F., we can easily deduce its value in C.G.S. units and degrees C. We note first that the units employed in the 777·2 value of J are not rational ; the energy unit, the ft.-lb., is in the British Engineers' system, while the mass unit used to define the B.Th.U. belongs to the F.P.S. system. The mass unit in the British Engineers' system is the slug or g pounds, and the value of J in this system is therefore $777{\cdot}2 \times 32{\cdot}2$ ft.-lbs. per slug per degree F. To convert this value to the C.G.S. measure of J in ergs per gramme per degree C., we must multiply by the square of 30·48, the number of centimetres in a foot, and divide by 5/9 the number of degrees C. in one degree F., the time dimension being irrevelant as this time unit is the same in the two systems. Thus J in C.G.S. units is :—

$$777{\cdot}2 \times 32{\cdot}2 \times (30{\cdot}48)^2 \times 5/9 \text{ ergs per gramme per degree C.}$$

$$= 7{\cdot}772 \times 3{\cdot}22 \times (3{\cdot}048)^2 \times 5/9 \times 10^5 \text{ ergs per gramme per degree C}$$

$$= 4{\cdot}18 \times 10^7 \text{ ergs per calorie.}$$

The appearance of the dimensional symbol θ for temperature in the dimensional formulæ for thermal quantities depends upon how quantities of heat are measured. The thermal conductivity of a substance, for instance, is defined as the quantity of heat per second passing between opposite faces of a unit cube of the substance with unit temperature difference. If heat is measured in thermal units, it has the dimensions $M\theta$ and the dimensional formula for thermal conductivity

(*Concluded on page* 274)

Sheathings for Trailing and other Flexible Cables for use in Coal Mines* Part I

By B. B. EVANS, B.Sc., F.R.I.C., F.I.R.I.

Henley Research Laboratories

FROM time to time, papers dealing with various aspects of trailing cable design and use have been presented to this Association. These have dealt with the subject from the standpoint of the engineer but this paper will explain how the chemist sees some of the problems and how he attempts to deal with them. In particular, materials which have been used or investigated for sheathing purposes over the past few years will be discussed. For many years prior to the late war, natural rubber was used for this purpose but even before the war, several synthetic rubber-like products which, in certain respects, were better than natural rubber were becoming available. The acute shortage of rubber following the loss of Malaya caused a number of these synthetics to be investigated and used merely to save rubber quite irrespectively of any technical superiority over the natural product.

Now that supply conditions have once more become normal, it is possible to review the merits or otherwise of the natural and synthetic materials so as to form an opinion on which are likely to be used or rejected.

Properties Required

A discussion of technical merits implies that the required properties are known and that means of measuring them are available. Firstly, let us consider the properties which it seems are required in a sheathing ; there may, however, be some divergence of opinion as to the relative importance of some of these properties based on practical experience.

As sheathings are used to give mechanical protection to the cores, the first requirement seems to be that a sheath must have the maximum resistance to cutting and abrasion.

It also seems important that the sheath should have the maximum resistance to tear.

Next, stiffness and resilience seem to come into the picture ; for instance, the sheath must not be so stiff as to make the cable difficult to bend, nor, on the other hand, must it be so springy or resilient as to prevent the cable from staying laid or coiled in the position which the operative may require. The property of " resilience " or more correctly, its opposite, cold flow, is also of importance when making cable connections, for the sheathing must not flow where it is gripped in sockets.

A trailing cable is heavy to drag about so that, other things being equal, the specific gravity of the sheathing compound should be kept down to the minimum.

Another important feature of the sheath is that it must be non-corrodible by, and resistant to, the passage of acid water so as to protect the metallic earthing screens against corrosion.

Lastly, but not necessarily least important, it is an advantage if the sheath is fire-resistant or self-extinguishing. If a fire occurs in one part of a mine, the likelihood of this being conveyed to another part of the mine by the cable is reduced if it has a self-extinguishing sheath. On the other hand, if by some means, open sparking occurs from a cable in a gassy mine, the mere use of a self-extinguishing sheath will not prevent an explosion.

Materials Available

Undoubtedly the nearest approach to a material having the properties outlined, lies in the use the chemist can make of natural rubber and rubberlike material and it is proposed to discuss four materials which have reached the stage of commercial production and availability. These are :—

(1) natural rubber ;

(2) the synthetic rubberlike material known prior to the war as Neoprene and during the war as GR-M and now as Polychloroprene;

(3) a second synthetic rubber known before the war as Buna S and during the war as GR-S ;

and (4) Polyvinylchloride (P.V.C.)

Before describing the chemistry of these materials, it should be noted that all four belong to a broad group of substances usually described as " high polymers " and perhaps it would be useful to explain what is meant by a " polymer."

It is generally known that the smallest entity of any chemical element such as carbon, hydrogen and chlorine, etc., is called an atom ; many of these atoms have chemical affinities for each other and combine to form molecules. The simplest organic molecule is

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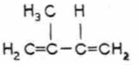
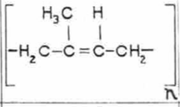
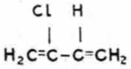
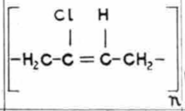
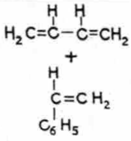
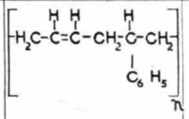
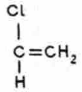
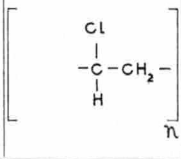
*A paper read before the Institution of Mining Electrical and Mechanical Engineers. 2nd January, 1947.

TABLE 1.

Chemical Classification of Natural Rubber and Synthetic Rubber Like Materials

MONOMER			POLYMER	
NAME	STATE AT ROOM TEMPERATURE	CONSTITUTIONAL FORMULA	CONSTITUTIONAL FORMULA	COMMERCIAL PRODUCT
ISOPRENE (METHYL—BUTADIENE)	LIQUID B.P. 37°C	 $H_2C{=}\overset{H_3C}{\overset{\mid}{C}}-\overset{H}{\overset{\mid}{C}}{=}CH_2$	 $\left[-H_2C-\overset{H_3C}{\overset{\mid}{C}}=\overset{H}{\overset{\mid}{C}}-CH_2-\right]_n$	NATURAL RUBBER
CHLOROPRENE (CHLORO—BUTADIENE)	LIQUID B.P. 60°C	 $H_2C{=}\overset{Cl}{\overset{\mid}{C}}-\overset{H}{\overset{\mid}{C}}{=}CH_2$	 $\left[-H_2C-\overset{Cl}{\overset{\mid}{C}}=\overset{H}{\overset{\mid}{C}}-CH_2-\right]_n$	NEOPRENE GR-M (POLYCHLOROPRENE)
BUTADIENE (DI-VINYL) + STYRENE (VINYL—BENZENE)	GAS B.P. 1°C + LIQUID B.P. 146°C	 $H_2C{=}\overset{H}{\overset{\mid}{C}}-\overset{H}{\overset{\mid}{C}}{=}CH_2$ + $\overset{H}{\overset{\mid}{\underset{C_6H_5}{\underset{\mid}{C}}}}{=}CH_2$	 $\left[-H_2C-\overset{H}{\overset{\mid}{C}}=\overset{H}{\overset{\mid}{C}}-CH_2-\overset{H}{\overset{\mid}{\underset{C_6H_5}{\underset{\mid}{C}}}}-CH_2-\right]_n$	G.R.S. BUNA. S.
VINYL CHLORIDE (ACETYLENE HYDROCHLORIDE MONO-CHLORO-ETHYLENE)	GAS B.P.-14°C	 $\overset{Cl}{\overset{\mid}{\underset{H}{\underset{\mid}{C}}}}{=}CH_2$	 $\left[-\overset{Cl}{\overset{\mid}{\underset{H}{\underset{\mid}{C}}}}-CH_2-\right]_n$	POLYVINYL CHLORIDE P.V.C.

formed by the joining of four hydrogen atoms with one carbon atom to give methane, (CH_4) which is known as " firedamp."

When carbon, hydrogen, and other elements are combined in certain ways, we obtain molecules which can be caused to join themselves together by suitable treatment. This process is known as polymerization. The basic molecule or unit is known as the "monomer," while the built-up product is known as the " polymer." In some cases the polymerization of two different types of molecule may be caused to proceed at the same time in the same vessel. This process is known as copolymerization and the product is known as a " copolymer."

The chemist may be regarded as a molecular architect ; he is becoming increasingly able to cause suitable molecules to built themselves up into any desired structure during polymerization so that the final products will have, to a large extent, predetermined characteristics. It will be realized then, that in many cases the physical properties of these polymers depend, not so much on the proportions of different elements present, but on their molecular architecture. A simple illustration of this is in the well known difference in properties between natural rubber and gutta percha. In both cases one has in the monomer, eight atoms of hydrogen combined with five atoms of carbon, but whereas rubber shows the well-recognized properties of elasticity, gutta-percha is virtually devoid of this property and this difference is quite reasonably attributed to the structure which has been taken up during natural polymerization in the tree.

Of the four materials mentioned, natural rubber, GR-M and GR-S are closely related chemically. It is pleasing to realize that the early fundamental work on the chemistry of natural rubber, upon which the later superstructure of the synthetics was built, was, in fact, carried out in this country. As far back as 1860, Williams isolated the basic hydrocarbon or monomer of natural rubber and called it isoprene. Some years later, Sir William Tilden showed that isoprene could be obtained by the thermal decomposition of common turpentine and, further, that isoprene could be caused to polymerize, giving artificial rubber. Isoprene belongs to a group of hydrocarbons known as di-olefines, or as they are more usually called, dienes. The carbon and hydrogen in the molecules of this group of hydrocarbons are combined in such a way that they polymerize fairly readily, so that it was a logical step for chemists in other countries to investigate the polymerization of other dienes. The simplest member of this group, and the one most readily obtainable is that known as butadiene. Now, the monomer of natural rubber (isoprene) is itself a derivative of butadiene, being known chemically as methyl-butadiene ; the monomer of GR-M is chloro-butadiene and the inclusion of chlorine into the molecule has an important effect which will be referred to later. It would be expected that a synthetic rubber would be obtained by polymerising butadiene itself and, in fact, rubbers of this type have been produced commercially. However, they were exceedingly tough and difficult to process on the types of machinery used for processing natural rubber. This seems to be due to the rather complex structure assumed by the butadiene during polymerization. It has been found that this structure and hence the physical characteristics of the final product, can be more readily directed along desired lines by addition of other materials, of which styrene is the most effective. Thus, the copolymerization of butadiene and styrene yields the material produced in vast quantities during the war by America and known as GR-S, which is fundamentally the same material as was produced by the Germans in pre-war days and called by them " Buna S." It may be of some interest to note that styrene can be obtained from coal.

Vinyl chloride is the monomer from which polyvinylchloride (P.V.C.) is obtained. Although being, as it were, a first cousin to those just discussed, it is rather simpler and can be regarded as being derived from ethylene or acetylene. Taking ethylene, which is the simplest member of a series of hydrocarbons known as the olefines, and replacing one of the hydrogen atoms by chlorine, we obtain monochlorethylene, or as it is usually called, vinylchloride. The same material can be obtained by treating acetylene under suitable conditions with hydrochloric acid. The chemical relationships of the foregoing and the commercial products obtained from them by polymerization are summarized in Table 1.

Calculations based on measurements of molecular weight show that something of the order of 2 000—5 000 monomers join up to form one of these " high polymer chains " and to assist in forming an idea of the sort of dimensions being considered, the length of these chains has been calculated at about $1-2\times10^{-4}$ cm.

As has been stated earlier, monomers may assume various structures during polymerization and the particular structure built up will determine many of the physical characteristics of the products. The view generally accepted today, based on evidence such as X-ray examination, is that these particular monomers take up a long chain structure during polymerization and many of the rubberlike properties of the final products are attributed to this fact. Thus while the chains are regarded as being merely intertwined in the unvulcanized state, so that the material remains plastic, it is visualized that when vulcanization occurs, the vulcanizing agent really acts by locking the different chains and parts of chains in position. Thus the materials are no longer plastic ; they require greater force to deform them and will return to their original dimensions when the deforming forces are removed, i.e., they show the typical characteristics associated with vulcanized rubbers. The current theories have been reviewed and discussed more fully by Pollett.*

None of the synthetics is chemically identical with rubber and though they all have the same type of structure, there is good reason, as will be seen later, for believing that the synthetics have not absolutely the same structure as natural rubber. Therefore, the former are more correctly described as materials chemically related to natural rubber and which exhibit many of the properties associated with the natural product.

It will also be noticed that both GR-M and P.V.C. contain chlorine, actually about 35% and 55% respectively, whereas the other two are ordinary hydrocarbons, i.e., compounds containing only carbon and hydrogen. It is this chemical difference which accounts for the fact that whereas rubber and GR-S will continue to burn if ignited, the other two materials are self-extinguishing.

So much for the basic chemistry of these materials. Practical engineers are probably more interested in the way this chemistry is applied in practice so it is now proposed to deal with this aspect of the subject. The monomers which have been considered can be obtained by a variety of reactions in the laboratory, but when it comes to large-scale production, it is obviously necessary to choose materials which are in ample supply and comparatively cheap, and to use chemical routes and reactions which are relatively simple. " Relatively " is an important qualification because none of these polymerization reactions is simple, and unless close control of numerous factors is exercised, all sorts of side reactions are liable to proceed and to give unwanted products. However, with this qualification, Fig. 1 shows the chemical routes by which the final products are reached.

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*" DISTRIBUTION OF ELECTRICITY," April, 1945, p. 354, July, 1945, p. 19, Oct., 1945, p. 48).

So far as natural rubber is concerned, nature provides this in the rubber tree, by a process we do not understand ; in the natural state the rubber is already polymerized in the form of a water emulsion usually referred to as rubber latex. To obtain the rubber, the emulsion is broken, usually by the addition of a weak acid, such as acetic ; this results in coagulation of the rubber, the water phase is poured away, the coagulated rubber washed and dried to give the more or less familiar raw rubber of commerce.

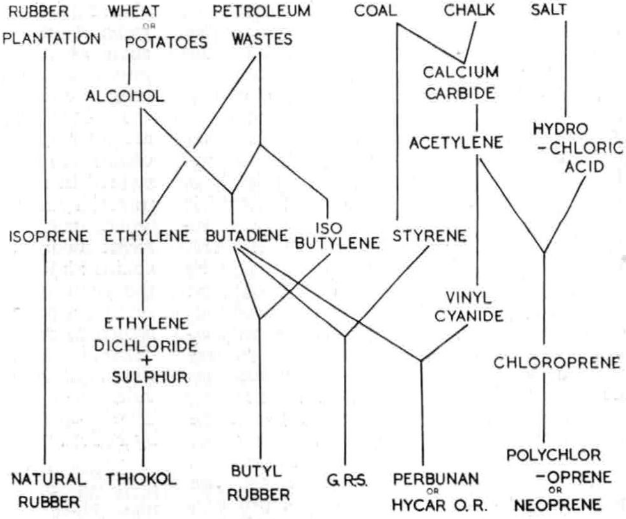


FIG. 1.

Chemical Routes to Natural and Synthetic Rubber.

The starting materials for synthetics may be petroleum, wheat or potatoes, chalk, coal and salt, depending on the availability, cost, and the type of synthetic which is aimed at. From wheat or potatoes we can obtain alcohol which, by a series of chemical reactions, is convertible into butadiene. This is a relatively expensive route by which to obtain butadiene ; this fact, together with the world shortage of grain, has led to its abandonment. Waste petroleum products, obtained from the refining of the petroleum and then put through what is known as a cracking process, involving treatment at high temperatures, can again be converted into butadiene. This is, of course, a very cheap route for any country such as America, having a large petroleum industry. Alternatively, from coal and chalk we can obtain calcium carbide and this, when treated with water, produces acetylene, which is a most versatile raw material and forms the starting point of a whole range of synthetic products other than those under consideration. However, by one form of chemical treatment, acetylene can be converted into butadiene.

Metallic sodium was used as a catalyst to speed up the polymerization for some of the early synthetic rubbers and when it is remembered that BU- are the first two letters of butadiene and " Na " is the chemical symbol for sodium, it is easy to see why the early German rubber was termed BUNA. In passing, it is of interest to note that a patent for the use of sodium as a catalyst for polymerizing di-olefines, was obtained in this country in 1910 by Matthews and Strange.

For reasons which have been mentioned earlier, these simple polymers were abandoned and so for producing the latest material of this type, coal is utilized to provide styrene. Mass polymerization, using sodium as catalyst, has been abandoned in favour of emulsion polymerization in which three parts of butadiene and one part styrene are emulsified in water. When copolymerization has gone as far as desired (which is usually a matter of hours) it is stopped, and the " rubber " coagulated from the " latex," washed and dried, following the same general technique as for natural rubber. It should be explained that emulsion polymerization has been adopted not merely to copy nature but because it has been found that this method allows the process to be more readily controlled and thus to give a more uniform product.

Acetylene also forms a starting point for

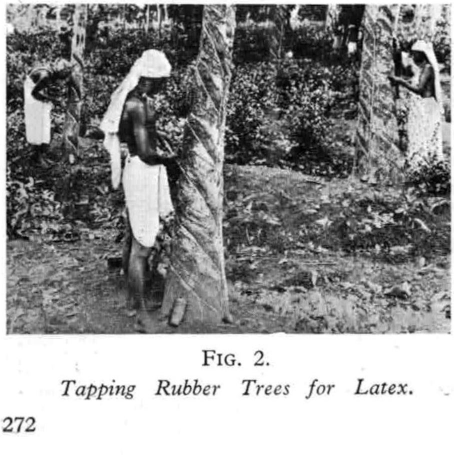


FIG. 2.

Tapping Rubber Trees for Latex.

GR-M and is itself first converted to vinyl acetylene, which is then combined with hydrochloric acid derived from common salt, resulting in the formation of chloroprene. This is then emulsified in water, polymerized to give GR-M latex, from which GR-M is obtained, again in a manner analogous to that for natural rubber.

The common chemical route by which polyvinyl chloride is manufactured is to treat acetylene with hydrochloric acid to give acetylene hydrochloride or, as it is more commonly called, vinyl chloride. This is then emulsified in water and submitted to emulsion polymerization. The polyvinyl chloride is then coagulated and obtained by a process very similar to that already described for the other materials.

It is now proposed to describe the methods whereby sheathings are produced from rubber and synthetics. The next steps in the manufacturing processes for rubber, GR-S, and GR-M are generally similar and can conveniently be considered together. It is fairly common knowledge that two things must normally be done to raw rubber to convert it into a technically useful material. In its raw state it is a plastic and an essential step is to convert it to an elastic product and, secondly, it must be strengthened. The first object can be achieved in various ways, but the one used almost universally is to add sulphur and heat the mixture in live steam at temperatures in the region of 140° C., when the rubber becomes vulcanized into the familiar elastic product.

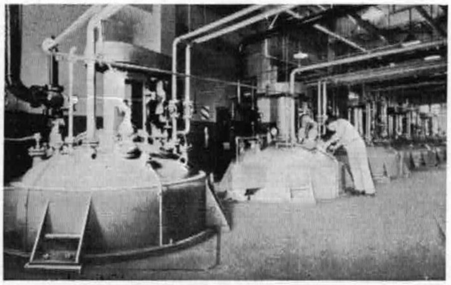


FIG. 3.

Reactor Tanks for Butadiene and Styrene.

Both GR-S and GR-M are converted from plastic to elastic materials by similar means, although in the case of GR-M, the actual chemicals added to effect the change are different from those for natural rubber and GR-S. Vulcanization would not, of itself, produce suitable compounds for sheaths and to obtain the desired strength, it is necessary to add reinforcing agents to the material, this being done at the same time as the addition of the vulcanizing agents. The procedure generally followed is to masticate the raw material either on open rolls or in an internal mixer where it becomes soft and plastic. At this stage, the reinforcing and vulcanizing agents are incorporated.

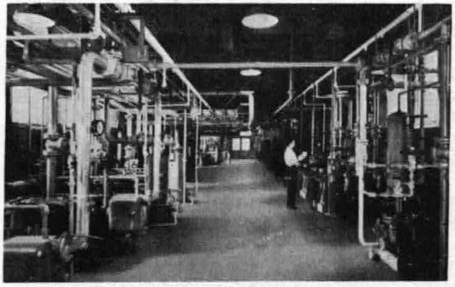


FIG. 4.

Pumps for Forcing Solutions and Latex from stage to stage in the Synthetic Process.

For sheathing purposes, the completed, but unvulcanized mix is extruded on the cable cores and the whole then placed in a vulcanizing pan, where under the action of heat from saturated steam at about 140° C., the sheath is vulcanized.

When it is realized that the term "vulcanized rubber" may include anything from a piece of soft cycle valve tube to a piece of hard ebonite, it will be clear that the physical properties of the vulcanized material are largely dependent on the nature of the added ingredients and many of the advances in rubber and allied technology have resulted from a study of the mechanism of reinforcement by compounding ingredients. It now seems to be established that the main factor governing reinforcement is the particle size, or surface area, of the added ingredient and the extent to which the particles are "wetted" by the rubber phase.

It is now recognized that to allow either natural rubber, GR-M or GR-S to develop the maximum resistance to abrasion, tearing or cutting, they must be reinforced with carbon black, which has a surface area of 7—10 acres per lb. and is really in a class by itself in this respect.

The credit for first discovering the outstanding reinforcing effect of carbon black on rubber must, in the author's opinion, go to the technical staff of the India Rubber and Gutta Percha Company of Silvertown, who applied their findings to the Palmer Cord tyre. Later it became generally recognized and there is no doubt that the long wearing life of modern tyre treads and similar products, such as cable sheaths, must be attributed to carbon black. So important is this material to the rubber industry, that a few details concerning its manufacture are of interest. It is produced by the thermal decomposition of natural gas, of which there are large quantities in America. About 1 000 cubic feet are burned to produce 1½ lbs. of carbon black, and when it is realized that in the years immediately prior to the war, America produced approximately 250 000 tons of carbon black per annum, it can be seen that this used up very large quantities of natural gas. In general, two methods are used, known as the Channel and Furnace processes respectively. In the former, the gas is burned from small jets and the flame allowed to impinge on cold steel surfaces termed channels ; the deposited carbon yields what is known as " channel black." In the furnace process, the natural gas is burned by a continuous process in furnaces at a temperature of 2 000—3 000° F., with a supply of air insufficient for complete combustion. The resulting black, plus air, is cooled and the carbon black is electrically precipitated. There are, of course, variations in each process to give a whole range of blacks for different purposes, but the two described, cover very broadly those used for the production of reinforcing blacks for rubberlike materials. Fig. 6 shows a typical furnace-black plant.

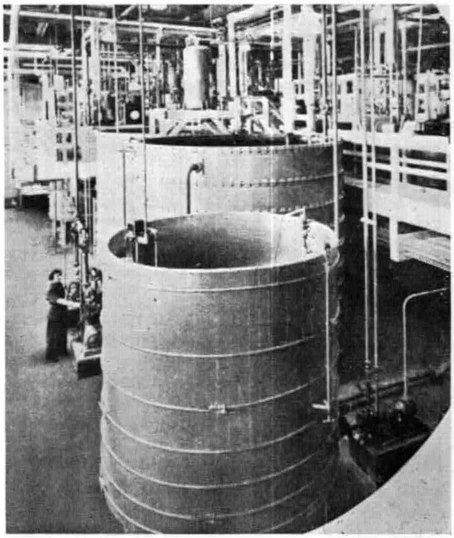


FIG. 5.
Tanks for Storage of Reagents and Coagulation of Latex.

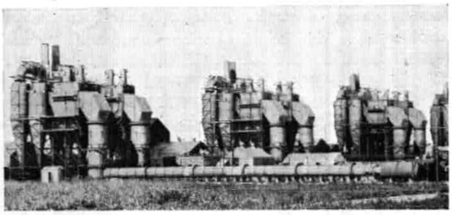


FIG. 6.
Furnace Black Plant

The technology of p.v.c. follows rather different lines. The polymer is commercially available as a fine white powder and to convert it to a flexible rubberlike product, the powder is mixed with certain organic liquids, known as plasticizers, which have a swelling action on the basic p.v.c. When the resulting mixture is heated to temperatures of 150° C.—170° C. for about fifteen minutes, the plasticizer causes the material to gel, resulting in the formation of a rubberlike material which is usually referred to as p.v.c. compound, to distinguish it from the basic polymer. A variety of plastizers is available and they play a large part in determining the physical characteristics of the resulting compound. The reason why one plasticizer imparts different properties from another is not fundamentally understood. Theories have been advanced and these are discussed by Harvey*. P.V.C. compounds differ in two ways from the other three types which have just be discussed. Firstly, p.v.c. compounds of the types in common use are not vulcanizable and hence cannot be changed from plastic materials into ones in which the elastic properties predominate. Secondly, attempts to reinforce them along the same lines as the rubber do not lead to the same result. For instance, although addition of carbon black to a p.v.c. compound does give some increase in tensile strength and tear resistance, the resulting product is so stiff as to be most difficult to process or use as sheathings.

*(" DISTRIBUTION OF ELECTRICITY," October, 1944, p. 318).

(*Continued from page* 268)

will be $ML\theta/L^2\theta T=M/LT$. If, however, heat is measured in dynamical units and thermal conductivity is expressed in, say, watts per centimetre per degree C., its dimensions will be $ML^2/T^2\times L/L^2T\theta=ML/T^3\theta$. The essential difference in the inherent natures of thermal conductivity, accordingly as it is specified in thermal or dynamical heat units, is rarely explained in the text-books.

The C.E.B. Nineteenth Annual Report

This report, which covers the year ending 31st December, 1946, presents the salient features of the Board's operation for that very difficult year and it does not gloss over the difficulties which confront the electricity supply industry for the next few years.

To the well known difficulties of unsuitable fuel, fuel restrictions, shortage of generating plant, and labour shortages for plant overhauls, the report mentions another irritant—the increasing complexity of procedure in respect to town and country planning and other controls in the sanctioning of new power-station sites.

Load shedding over more frequent and longer periods is inevitable during the next two or three years unless some measures for spreading the load are adopted.

The maximum demand met in 1946 (18th December) was 9 154 000 kW. The maximum estimated demand two days earlier was 10 130 000 kW, but only 8 961 000 kW could be supplied, for 16% of plant was out of commission for various reasons. The load factor rose from 45·1% in 1945 to 46·6% for 1946. The total units generated during the year by public supply stations in Great Britain was 41 240 million, 10·6% greater than for 1945. The 1946 output was 69·3% higher than that of 1938.

The Grid lines comprise 3 675 miles operating at 132 kV and 66 kV or lower voltages, the total mileage being substantially the same as for the previous year. The system includes 348 switching and transforming stations having an aggregate transformer capacity of 13 920 200 kVA.

A very substantial programme of reinforcement and extensions for the Grid has been put in hand, but delays in the delivery of materials is causing the work to fall into arrears. It is interesting to note that the 132 kV line projected from Neepsend to Staythorpe under this programme is to be constructed so as to be suitable for operation later at 264 kV.

The preference which has been given to war-damage repairs has necessitated deferment of some normal maintenance work.

The number of Selected Stations remains unchanged at 142. During the year, 305 000 kW of new plant was put into service against which 32 625 kW of old plant was derated or removed making the nett increase 272 375 kW and bringing the total installed capacity to 11 588 306 kW by the end of the year.

The Board have had sanctioned generating plant extensions of 1 532 500 kW for completion in 1950, which, together with formerly authorized extensions, brings the total of new generating plant either actually under construction or awaiting commencement of work to 5 892 700 kW.

The Board maintains close touch with new developments and hopes soon to be able to arrange for the installation of one or more 15 000 kW gas turbines. They are also in close touch with the development of atomic energy for electricity production.

Many types of new equipment have been out into service during the year. New gas pressure cables have been installed and satisfactory performance of those previously installed is reported.

The first 132 kV substation equipped wholly with air-blast circuit-breakers will soon be in service and new low oil-content switchgear having only 30 gal. of oil per phase has been brought into service, whilst other similar gear is under construction. The continued increase of generating capacity is focussing attention on the rapturing capacity of the system switchgear. Investigations have been made to find means of increasing the rated capacity of 1 500 MVA without incurring the expense of new circuit-breakers and as a result it has been possible to modify existing breakers to give a safe rapturing capacity of 2 500 MVA. It is hoped that this modification can be applied to all the original 132 kV circuit-breakers.

The original cone-grip joints for the ACSR conductors have deteriorated and are being replaced with hydraulically pressed-on steel and aluminium sleeves. As a result of the satisfactory suppression of vibration breakages on conductors, the spans on new 132 kV lines will be increased from 900 to 1 000 ft. with conductor tensions correspondingly increased to avoid increasing the tower heights.

The Board is establishing a research laboratory at Leatherhead which will serve as a " first-aid " establishment in respect of failures of Grid equipment and will facilitate research into operational problems. The resources of the N.P.L. and B.E.I.R.A. will continue to be utilized for more general research.

A new standard transformer specification, C.E.B.T. (1946), calls for impulse type tests on new transformers.

A 3-phase bank of testing-transformers has been ordered for use with an experimental line designed for operation at 400 kV. The data obtained will be used for the design of the 264 kV line previously referred to and also for possible higher voltage developments.

On the operational side, the report is necessarily deeply concerned with load shedding. It states frankly that several years must elapse before the balance between generating capacity and demand is restored, even with plant priorities and the removal of obstructions in the acquisition of new power-station sites.

(*Concluded on page* 276)

Problem Circle

THE solution to the triple acrostic given in Problem No. 327 in our April issue is :—

1.	Trai	Tres	S
2.	Respl	Enden	T
3.	Ext	Rud	E
4.	Emba	Ssag	E
5.	Sle	Epe	R

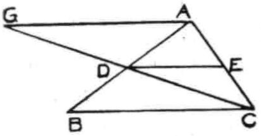
Notes : Uprights — TREES = boot-trees. TERSE = neat. STEER = ox = neet. 1. TRAI(T)RESS. 5. STANDING (under rails) ; RUNNING (sleeping-car) ; FOR FARE (passenger.)

This problem was evidently rather a teaser; for not many succeeded in solving it correctly although several got quite near. The winning effort was submitted by **Mr. T. MacCall, 19 Mill Road, Royston, Herts.**, to whom we award the 10/6 prize with our congratulations.

Here is Mr. Travers' characteristically snappy solution to his puzzle, set as Problem No. 328, which was to draw a line DE parallel to BC in any triangle so that $DB^2+EC^2=DE^2$.

Draw AG parallel to BC and equal to $\sqrt{(AB^2+AC^2)}$. Join GC ; then DE drawn parallel to BC is the line required. Proof ;

$$DE/AG=EC/AC=DB/AB$$
$$DE^2/AG^2=EC^2/AC^2=DB^2/AB^2$$
$$DE^2=EC^2+DB^2$$



A variety of constructions was submitted by competitors in which a line of length $\sqrt{(AB^2+AC^2)}$ was drawn, all of which gave correct answers, but none so terse as that we give.

We congratulate competitors on their efforts.

Once more the prize goes to India, to **Mr. P. S. Nilakantan, All India Radio, Trichinopoly, India,** whose solution of the problem secures the half-guinea.

We are again indebted to Mr. T. Carter for a novelty puzzle which competitors may like to try. It is to construct a square of letters in which rows and columns form words. The word in the first row of the square must be the same as that in the first column, and similarly for the second and third rows and columns and so on. Here is a simple example :—

M A R
A N Y
R Y E

Each letter is given a value according to its sequence in the alphabet, e.g., B=2, C=3 .... Z=26.

The value of the word in the first line is 32, in the second it is 40 and in the third 48, making the total 130.

Problem No. 329.

Competitors are asked to form a four-letter word-square, the words of which appear in a standard dictionary. The prize will be awarded to the result which has the highest total value for the four words.

Unless one is up to the tricks ; the next problem will keep one busy for a while.

Problem No. 330.

A gardener has a plant from which he takes 6 cuttings yearly after 2 years growth. He treats each cutting in the same way as the original plant. How many plants has he at the end of 10 years ?

The usual prize of half-a-guinea is offered for Problem 329 and also for the first correct solution of Problem 330 to be opened.

Solutions of these problems should be sent to the Editorial Offices " DISTRIBUTION OF ELECTRICITY," 51/53 Hatton Garden, London, E.C.1 by 30th August, 1947. The Editor's decision must be accepted as final.

(*Continued from page* 275)

The year has seen some increase in available labour for repairs, but nevertheless, during last December, generating plant idle through breakdown, overhaul, or unsuitable fuel averaged 15·9% against the 6% pre-war margin.

After giving facts and figures in relation to the then pending fuel crisis, the report discusses coal prices at length. The anomaly that the pithead unit price of heat supplied to generating stations increases with increasing ash content of the coal results from the flat-rate increases in coal prices. The poor quality and unsuitability of fuel and the continued use of out-of-date plant has increased fuel consumption to 1·506 lbs. per unit sent out in 1946 as against the pre-war figure of 1·430 lbs. The overall increase of fuel costs per unit is 137% above the 1938 figure, the average cost of coal being 45/3 per ton in 1946.

Further sections of the report deal with trading and finance.

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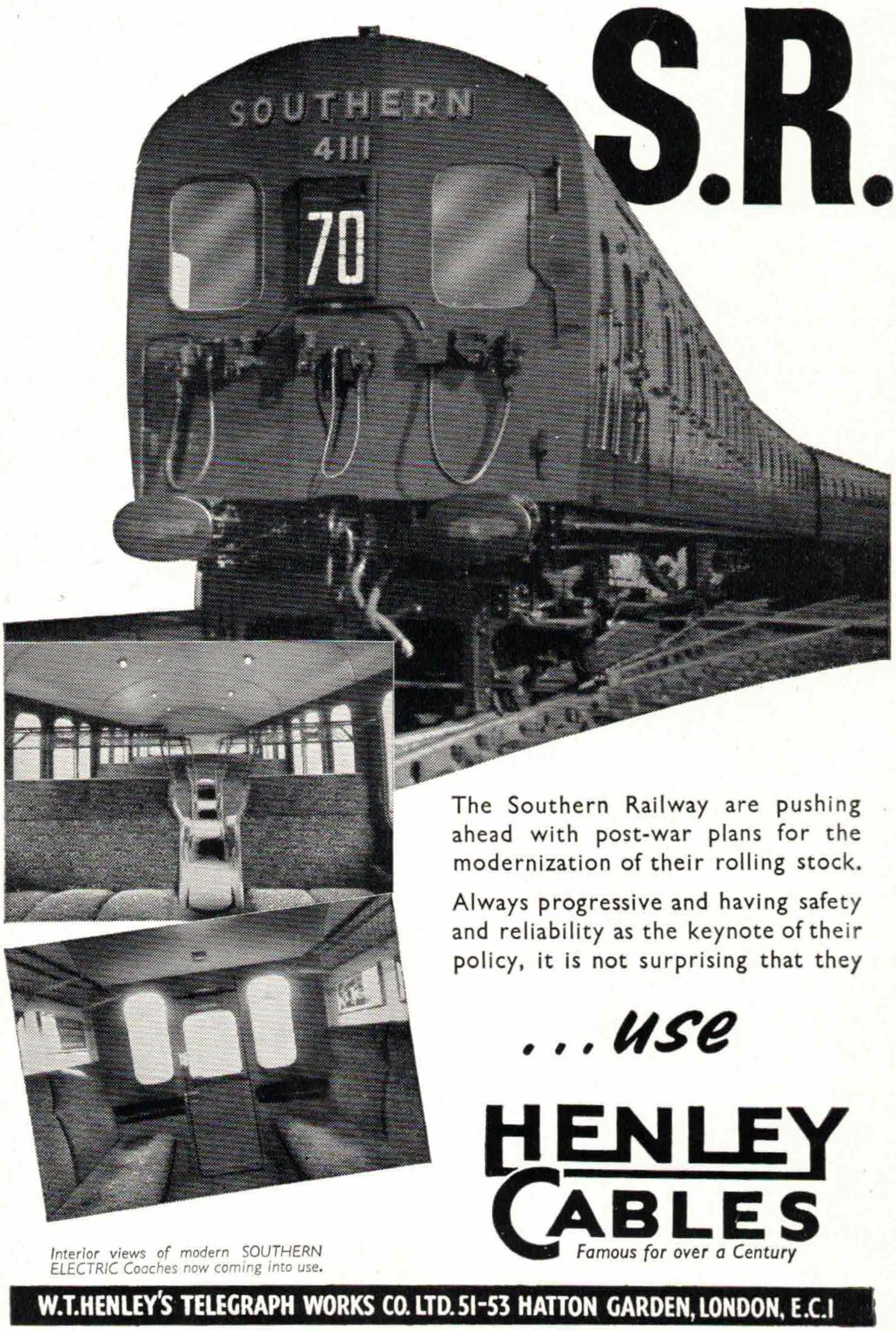
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